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PHETS LIGHTNING HARDENING PROGRAM: MISTY PICTURE EVENT

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June 1988

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Final Report

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AIR FORCE WEAPONS LABORATORY
Air Force Systems Command
Kirtland Air Force Base, NM 87117-6008

AFWL-TR-87-114

This final report was prepared by Mission Research Corporation, Albuquerque, New Mexico, under Contract F29601-85-C-0009, Job Order 672A0911, with the Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico. Mr David H. Hilland (NTAT) was the Laboratory Project Officer-in-Charge.

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ADA197171

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S): AMRC-R-919	5. MONITORING ORGANIZATION REPORT NUMBER(S): AFWL-TR-87-114
6a. NAME OF PERFORMING ORGANIZATION: Mission Research Corporation; 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION: Air Force Weapons Laboratory
6c. ADDRESS (City, State, and ZIP Code): 1720 Randolph Road, SE, Albuquerque, New Mexico 87106	7b. ADDRESS (City, State, and ZIP Code): Kirtland Air Force Base, New Mexico 87117-6008
8a. NAME OF FUNDING/SPONSORING ORGANIZATION; 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: F29601-85-C-0009
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO. 64312F; PROJECT NO. 672A; TASK NO. 09; WORK UNIT ACCESSION NO 11

11. TITLE (Include Security Classification)

PHETS LIGHTNING HARDENING PROGRAM· Misty Picture Event

12. PERSONAL AUTHOR(S)
Chapman, G.P.,; Gardner, R.L.; Lu, G.S.; Rison, W.; and Gurbaxani, S.H.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM Jan 87 TO Nov 87	1988, June	92

16. SUPPLEMENTARY NOTATION G. S. Lu is employed by the Defense Nuclear Agency/FCIE, KAFB, NM; W. Rison is employed by the New Mexico Institute of Mining and Technology, Socorro, NM; and S. H. Gurbaxani is with the American Science Foundation, Inc., PO Box 14353, Albuq. NM.

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Lightning, High explosives
04	02		Lightning protection, Instrumentation
			Surge protection, Sensors

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The Permanent High Explosive Test Site (PHETS) test-bed electrical topology and data flow are presented along with various equipments used in the topology. Using this information, recommendations are made to harden the test-bed instrumentation to electrical transients. These transients may be caused by lightning or electrostatic discharge. Specific attention is given to the junction box design, the shorting blocks, use of shielded cables, protection of the sensors, and the instrumentation bunker/container. Additional attention is given to the protection of personnel from lightning effects. Also it is recommended the optimum design is of a Faraday cage concept that completely encases the instrumentation from sensor to permanent recording medium. The optimum design should be prototyped and tested using the Precision Test-bed and current injection before general application to the PHETS.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION: Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL: David H. Hilland	22b. TELEPHONE (Include Area Code): (505) 844-9791; 22c. OFFICE SYMBOL: AFWL/NTAT

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

PREFACE

The Misty Picture high explosive test and previous high explosive tests have suffered the loss of sensors to lightning caused transients. This report is the result of Department of Defense (DOD) efforts to determine ways to prevent these losses. The information presented here comes from extensive observation of the Misty Picture high explosive event at the northern end of White Sands Missile Range. Additional considerations include damage or the potential for damage due to electrostatic phenomena to all parts of the instrumentation system, to personnel, and to expensive non essential hardware. This information will be available to all DOD personnel and their contractors and to all testing personnel from foreign governments.

Appreciation is due to numerous personnel of the Defense Nuclear Agency, the White Sands Missile Range, the Air Force Weapons Laboratory, and several contractors for their valuable inputs to this effort. Special appreciation is due to Mr. David Hilland of the Air Force Weapons Laboratory for his knowledgeable support of this effort.

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1.0 INTRODUCTION

1.1 PURPOSE

The purpose of this report is to describe the Permanent High Explosive Test Site (PHETS), its topology, its hardware, and lightning hardening and shielding efforts. Also, recommendations are made for near-term and far-term improvements to the test site.

1.2 BACKGROUND

The MISTY PICTURE (MP) high explosive (HE) test sponsored by the Defense Nuclear Agency (DNA) provided the nuclear weapons effects for measuring vulnerability and survivability of defense systems. The effects provided were ground shock, airblast, and simulated thermal environments. The data produced by this test enhance the knowledge of particular phenomenology and increase and refine the effects database.

The MP HE test was conducted at White Sands Missile Range (WSMR), 41 road miles southeast of Socorro, New Mexico and approximately 20 miles (32 km) south of the northern boundary of WSMR (Fig. 1). The location of PHETS is shown by Fig. 2. Ground zero (GZ) was located 500 ft southeast of the MINOR SCALE (MS) GZ. This location allowed the reuse of nearby roads, the instrumentation parks, the instrumentation radials, and most of the diagnostic camera bunkers. Because the crater of the previous test site was meticulously filled-in and repacked, it was possible to reuse the site for similar tests by moving the GZ only a nominal distance.

In previous HE tests of similar or smaller magnitude, sensors and transducers were lost for various reasons, but the prevalent cause was transients caused by lightning. In October 1983, 274 sensors were damaged or destroyed in the DIRECT COURSE (DC) test. In June 1985, 135 sensors were damaged or destroyed in the MS test. And in May 1987, 102 sensors were damaged or destroyed in the MP test.

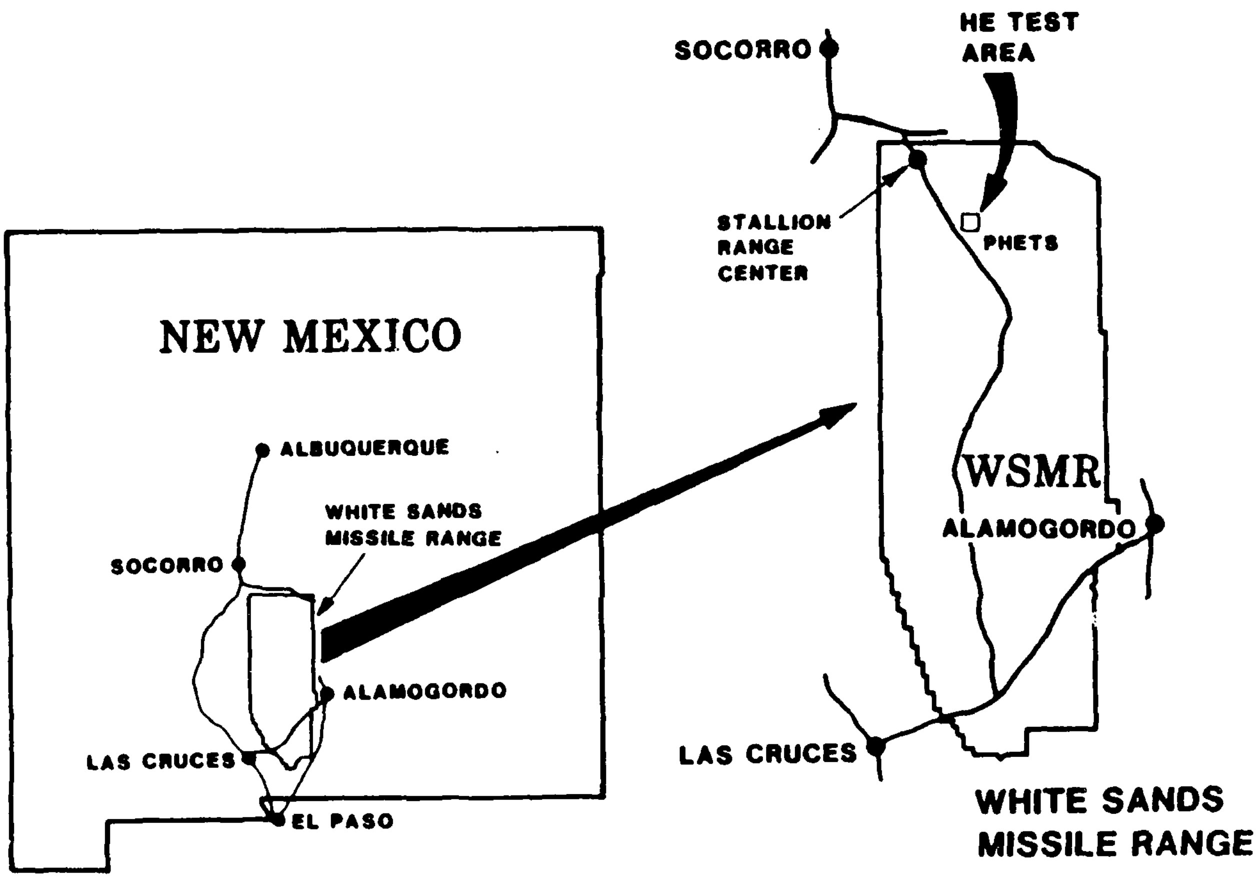


Figure 1. Location of the PHETS site.

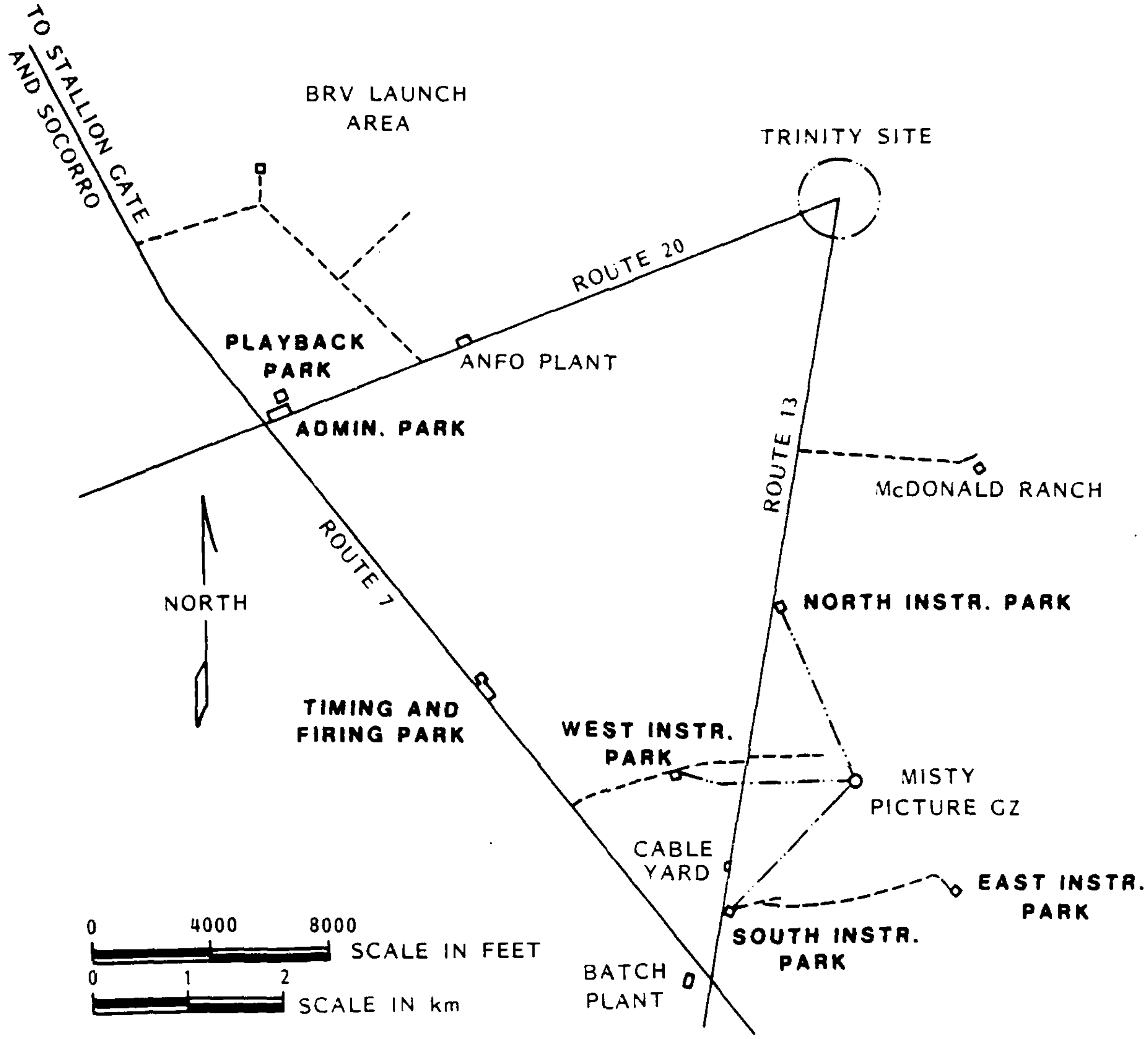


Figure 2. Location of the MP test on the PHETS site.

1.3 OVERVIEW

This report has been written in 5 sections to detail the hardening effort. The remainder of the report is, in summary:

a. Section 2.0 - TOPOLOGY

This section describes the electrical topology of the PHETS; including the detailed testbed, the data collection system, the special subsystems, the individual shelters used for environmental control and any other hardware that may contribute to the lightning threat.

b. Section 3.0 - EQUIPMENT LISTS

This section lists most of the component hardware in a linear fashion as the data would flow from the transducer to the data recording system.

c. Section 4.0 - RECOMMENDATIONS

This section describes the changes in procedures or hardware that are recommended. These changes should be ones that increase hardware hardness to electrical surges/transients, increase personnel safety, and enhance data quality.

d. Section 5.0 - CONCLUSIONS

This section briefly discusses the value of this lightning hardening effort.

e. LIST OF DEFINITIONS

This list gives several definitions of various terms and hardware germain to the treatment of lightning and electrostatic caused transients. Also, included are terms that help define PHETS hardware that is either vulnerable to damage or that may cause damage as a consequence of high current/voltage effects.

f. REFERENCES AND BIBLIOGRAPHY

Many references are given that are not used in this report. This has been done so that the reader who wishes to more thoroughly understand the theory of lightning and its consequences may find relative documentation. Also given are references to electromagnetic shielding.

g. APPENDICES

There are three appendices. Appendix A gives the theory and operation of the field mill system, an extremely important system for giving lightning potential warning 24 h/day. Appendix B gives detailed specifications on the two most used cables in the instrumentation topology. Appendix C gives the results and analyses of the earth grounding survey/testing; this information consists of ground resistance and earth resistivity.

2.0 TOPOLOGY

2.1 TESTBED

The airblasts of tests conducted at the WSMR instrumentation parks prior to the MS and MP tests were too strong for the standard instrumentation trailers. As a result, two things were done for the MS and MP tests. Eleven hardened bunkers (Fig. 3) were placed near the charge between the 3 and 10 lb/in^2 overpressure levels to allow remote digital recording of the various sensor outputs. In addition to the hardened bunkers, there are four instrumentation parks generally aligned with the cardinal compass directions. At each of the parks is a bermed structure similar to a quonset hut which houses a Recording Oscilloscope Sealed Environment System (ROSES). (The ROSES name comes from the use of this unit at the Nevada Test Site (NTS). This unit was used primarily as a cabling node and was not sealed in the NTS sense. Also, a large trailer located at the West Instrumentation Park was used to record analog data. This trailer was placed inside the Instrumentation Park's bermed structure (Fig. 4). The North, South, and East Instrumentation Parks contained the ROSES only.

The recording facilities at both the bunkers and parks were unmanned and were configured to operate remotely. The closest manned site was the old DIRECT COURSE administration park, which was used for the MP Timing and Firing (T&F) Park. DNA provided 1365 digital and 243 analog channels for recording the MP experimental data. All of the digital recordings were made at the instrumentation bunkers. Some other manned instrumentation trailers, such as, the thermal radiation simulator (TRS) control and helium control trailers, were also located at the T&F Park. This park is located about 11,200 ft west of the GZ and was exposed to about 0.7 lb/in^2 overpressures.

The Administration Park of MISTY PICTURE (Fig. 5) was the same one used for MINOR SCALE. It is located on the northeast corner of the intersection between Route 7 and Route 20. This is northwest of MP GZ. Co-located with the Administration Park is the Playback Park (Fig. 6). This trailer with

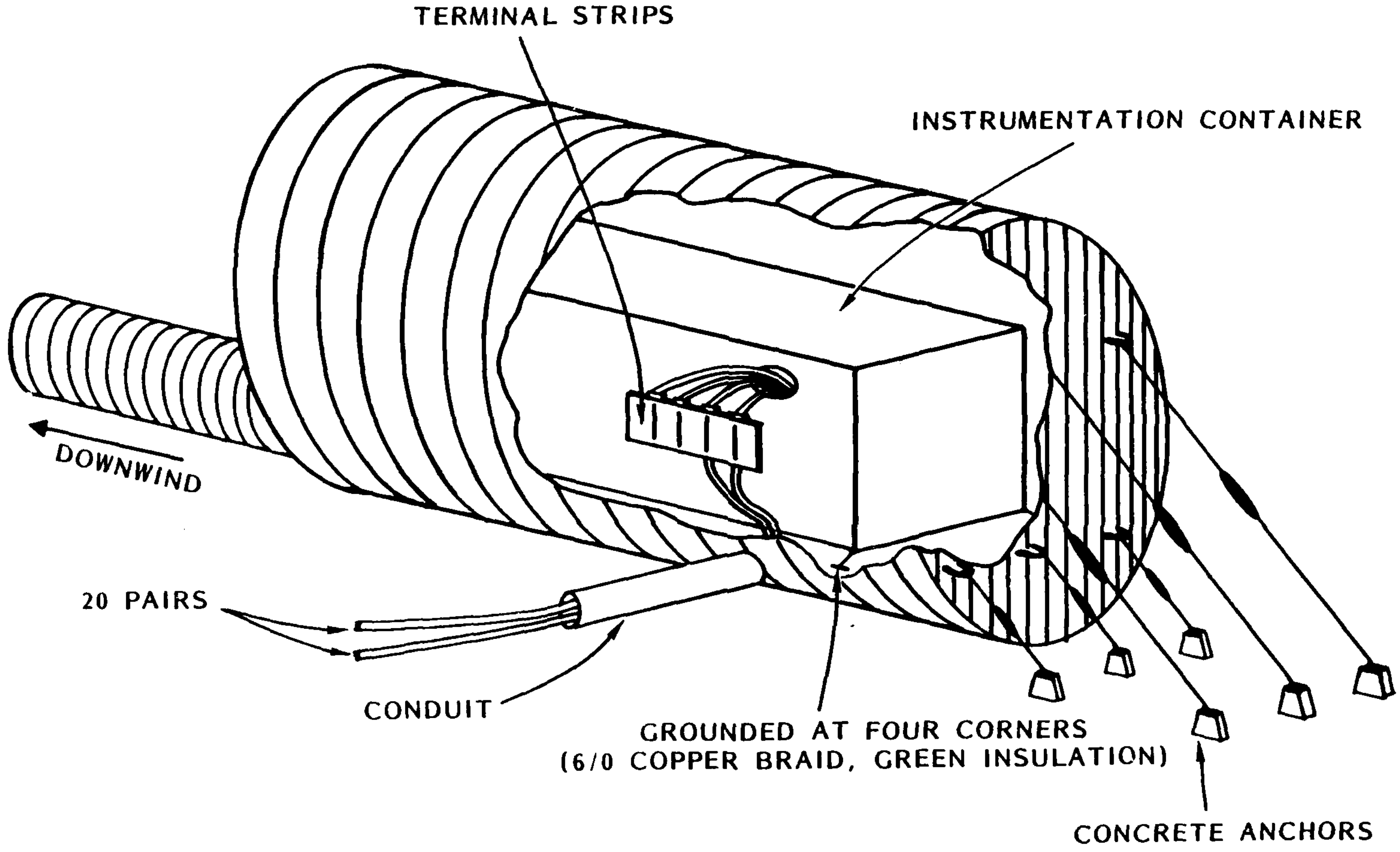


Figure 3. Instrumentation bunker without berm.

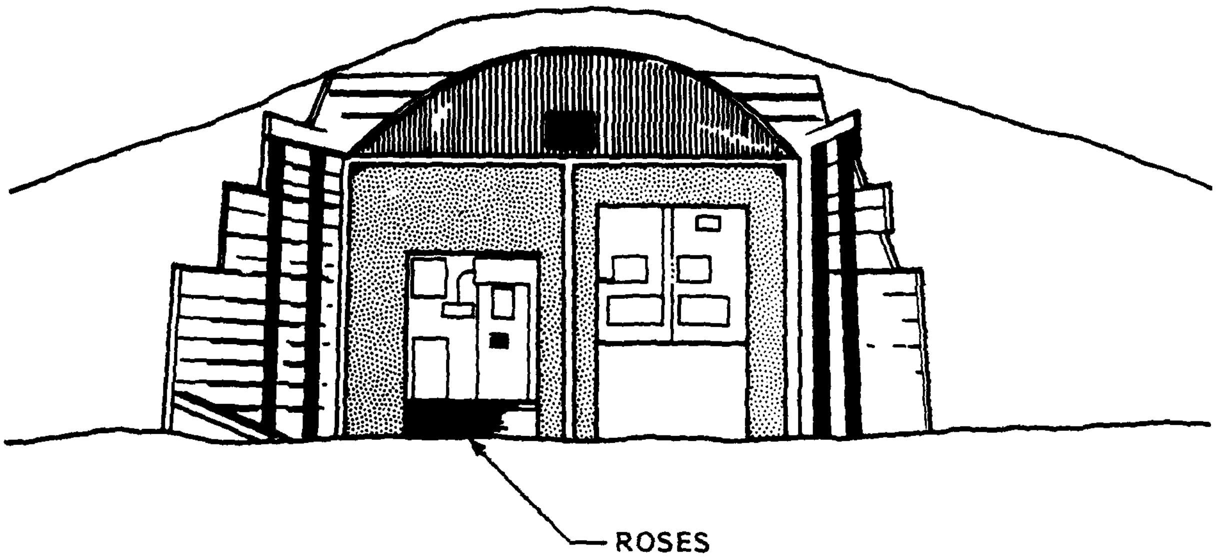


Figure 4. West Instrumentation Park.

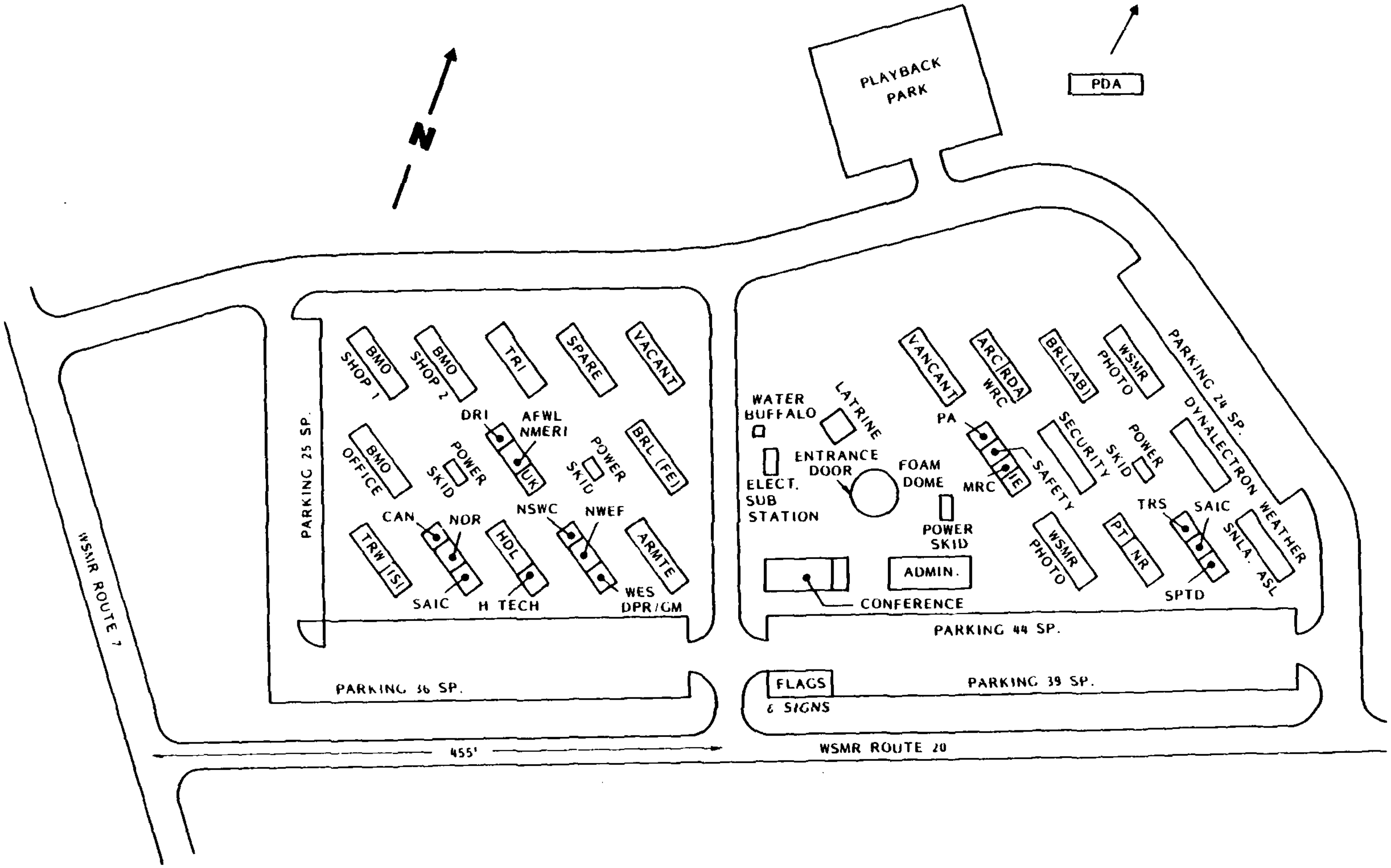


Figure 5. Administration Park.

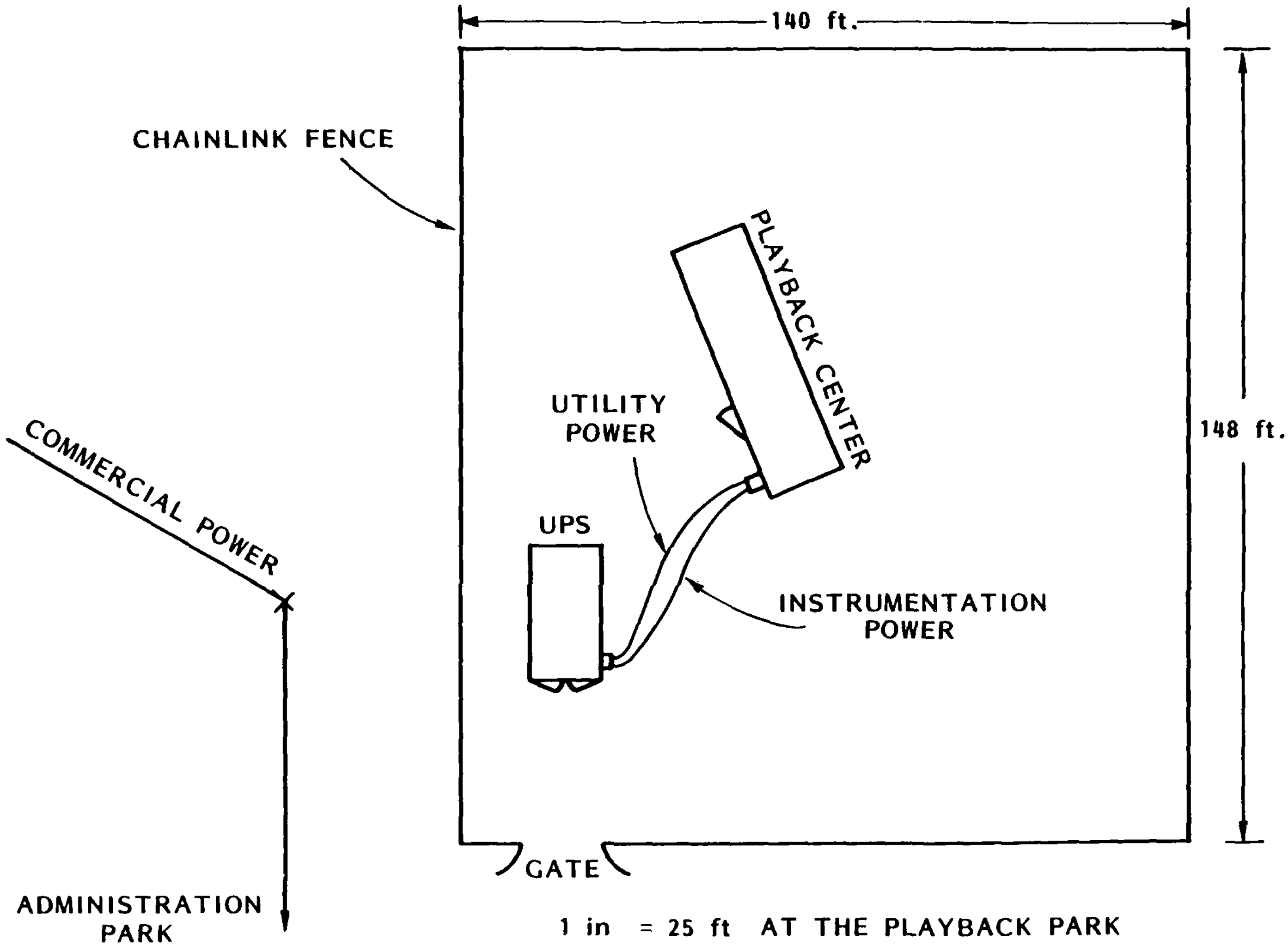


Figure 6. Playback Park.

its uninterruptable power supply was located on the Northeast edge of the Administration Park (Fig. 5).

At the Playback Park, all of the digital data were collected from each of the bunkers within minutes of the detonation at GZ. This was done by using fiber optic links to each bunker which transmitted the digitized data from each test channel digitizer to a VAX computer located at the Playback Park. Note: As the PHETS matures, the Playback Park will be named the Command and Control Center to reflect the integration of the Timing and Firing Park into the Playback Park located on the Northeastern boundary of the Administration Park.

2.2 DATA FLOW

Data from transducers in the testbed are transmitted through cables to recording equipment in the instrumentation containers inside the instrumentation bunkers. The analog data are converted to digital form and the information is stored in the transient data recorder (TDR) in the instrumentation container. These data are then interrogated by a PDP-N-23 digital microcomputer co-located with the TDR and by a VAX 750 minicomputer located in the Playback Park. In addition, the VAX is used to get quick look data. Both of these systems have recording media for saving the data. The data are then reduced to a useful form. Thus, it is seen that there are four parts to the data acquisition system: transducers to measure the physical parameters; a transmission system (cables and signal conditioners); recording devices; and data reduction processes. Figure 7 shows the typical data flow process.

Figure 8 shows the T&F cable layout without complete detail but is representative of requirements. The fanout, of which there are several, provides T&F information to cameras, thermal radiation simulators, time of arrival detonation system (TOADS), etc. The T&F system provides the data for initiating the explosive, the start time for recorders, time codes for recording with data, etc.

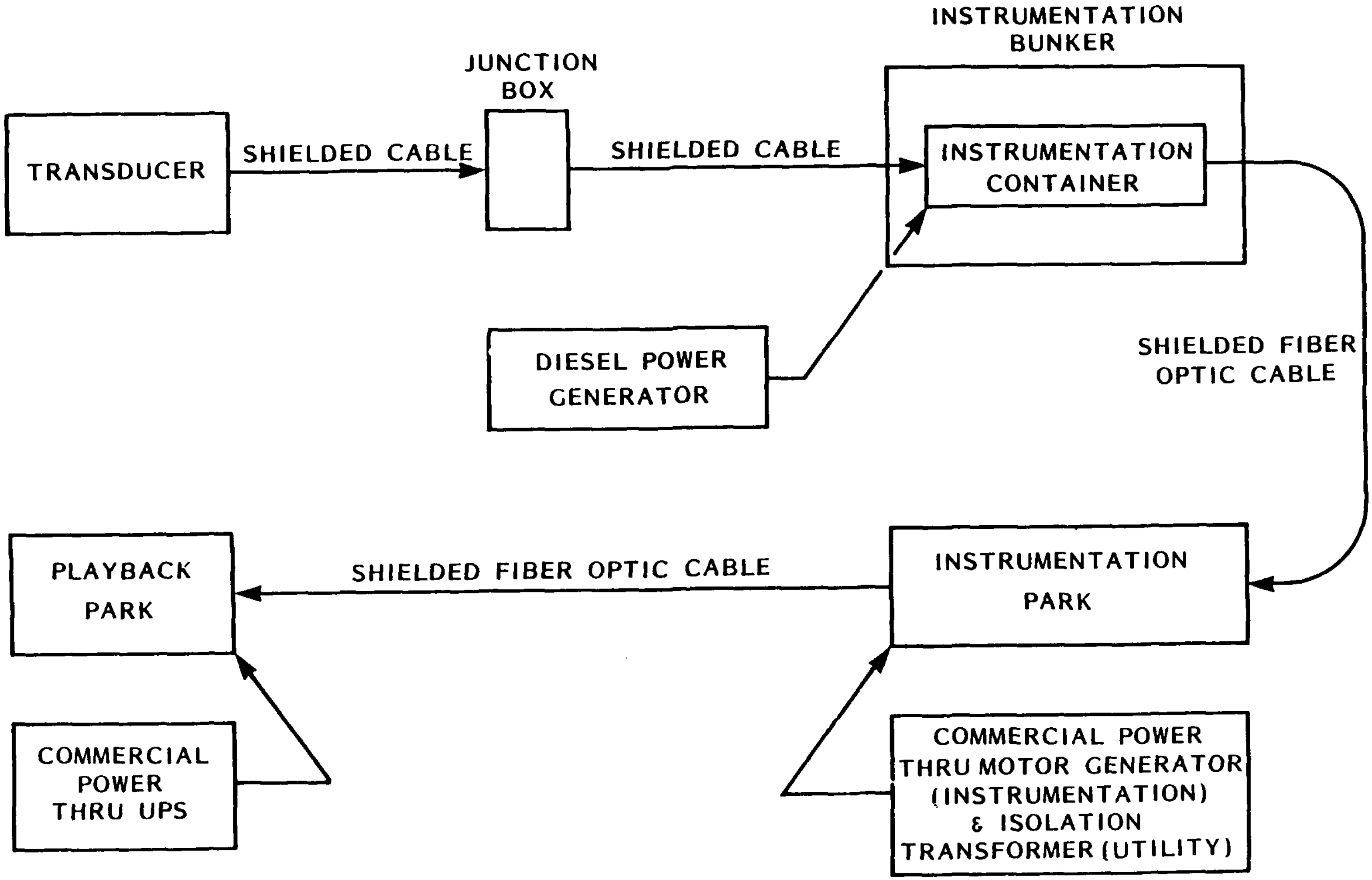


Figure 7. Typical data flow.

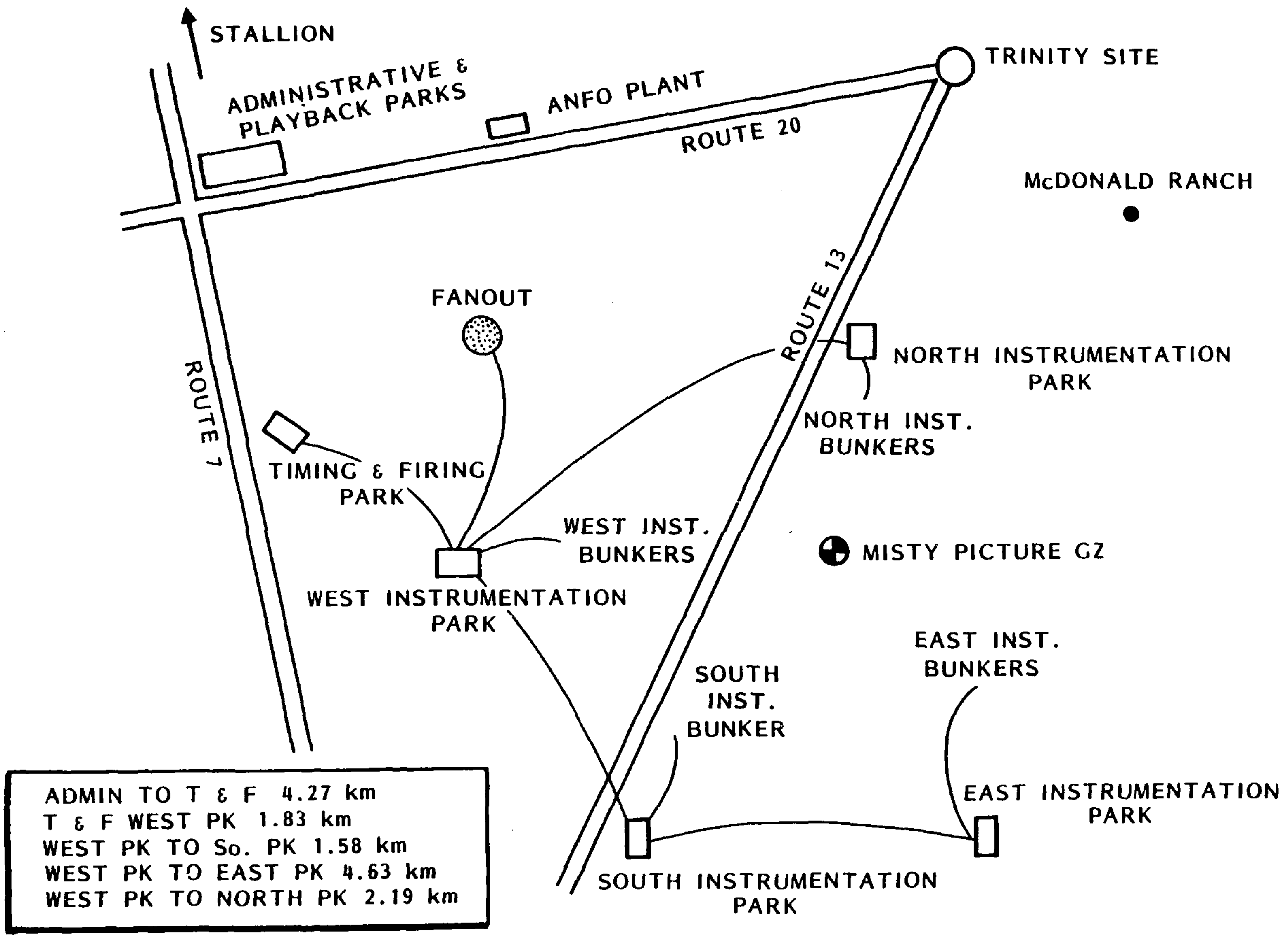


Figure 8. Timing and firing cable layout.

Figure 9 shows the commercial power distribution layout on the testbed. There are five substations associated with the commercial power. This system allows distant transients, usually lightning caused, to enter the testbed area.

Figure 10 shows the signal wiring layout for the Field Mill system. The power for the remote Field Mill units came from surge protected commercial power at the Administrative, North, and South Parks. Appendix A completely describes the Field Mill system and the associated warning sirens.

Figure 11 shows the fiber optic cable layout. The cable has a metal shield for environmental protection. This system has two-way communications with each instrumentation container. The software associated with the VAX mini computer has the capability to interrogate the data contained within each Instrumentation Container to include TDR setup configuration, TDR data, recorded data, etc. The objective of this system is to get near real time quick-look data from all the recorded experiments soon after the high explosive detonation.

Figure 12 shows the expansion of the data flow block diagram to show the explicit topology of a typical data channel. The usual configuration is for several of these data channels to be interconnected in a tree structure. As long as the tree structure (i.e., no loops) is maintained there is no additional susceptibility due to the additional channels.

Following Fig. 12, the data path starts as the signals from the transducer bridge are sent along four wires inside a shield. This cable is called a DNA Quad. The shield is typically not connected to the sensor. The quad carries the signal to the junction box where other quads from other sensors are connected to a terminal strip for connection to several 20-pair cables that take the signals to the Bunker. A junction box is only a weather protection device and is used for a convenient disconnect point. From an electromagnetic point of view it is entirely open. Quad shields enter the box, further defeating any possible shielding effectiveness. The junction box is often grounded.

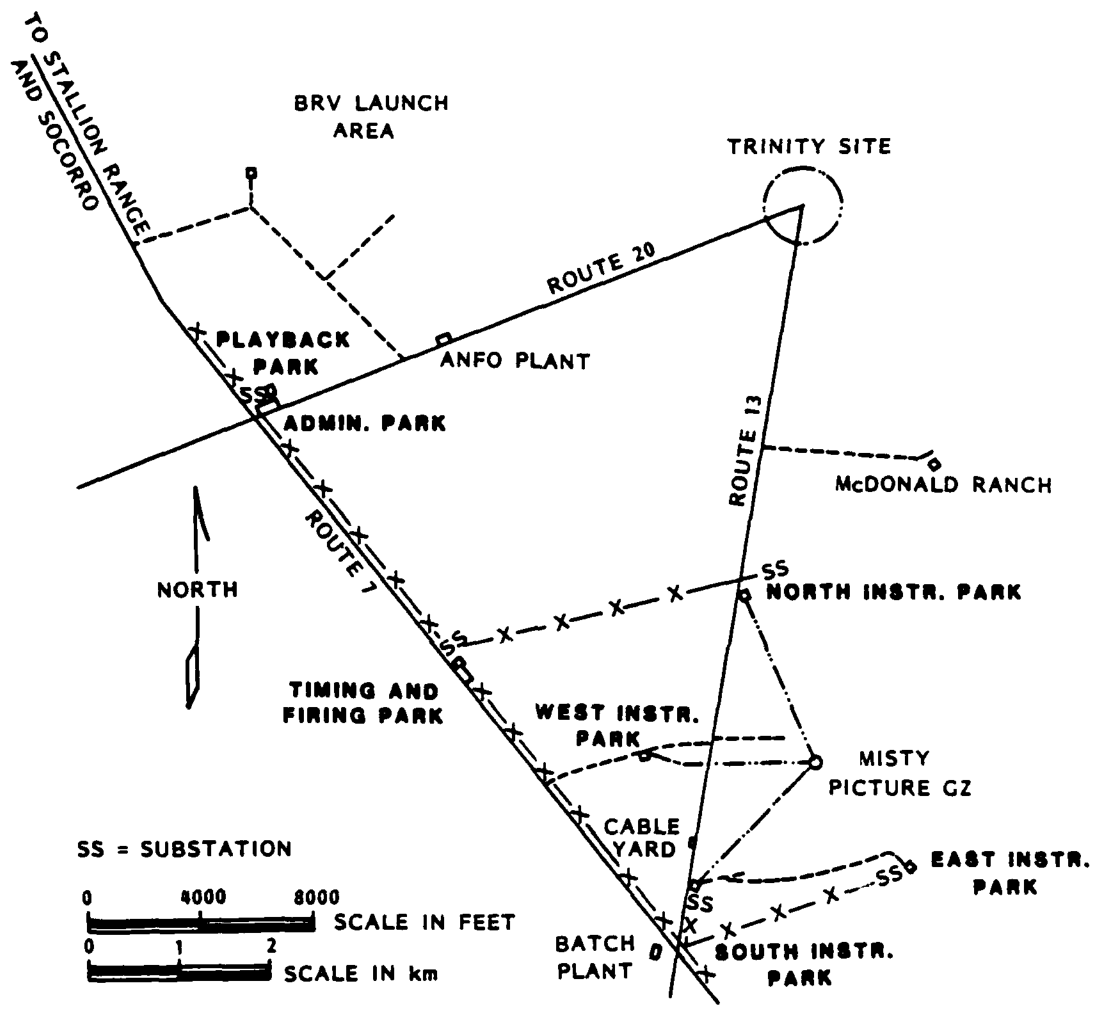


Figure 9. Commercial power distribution at PHETS.

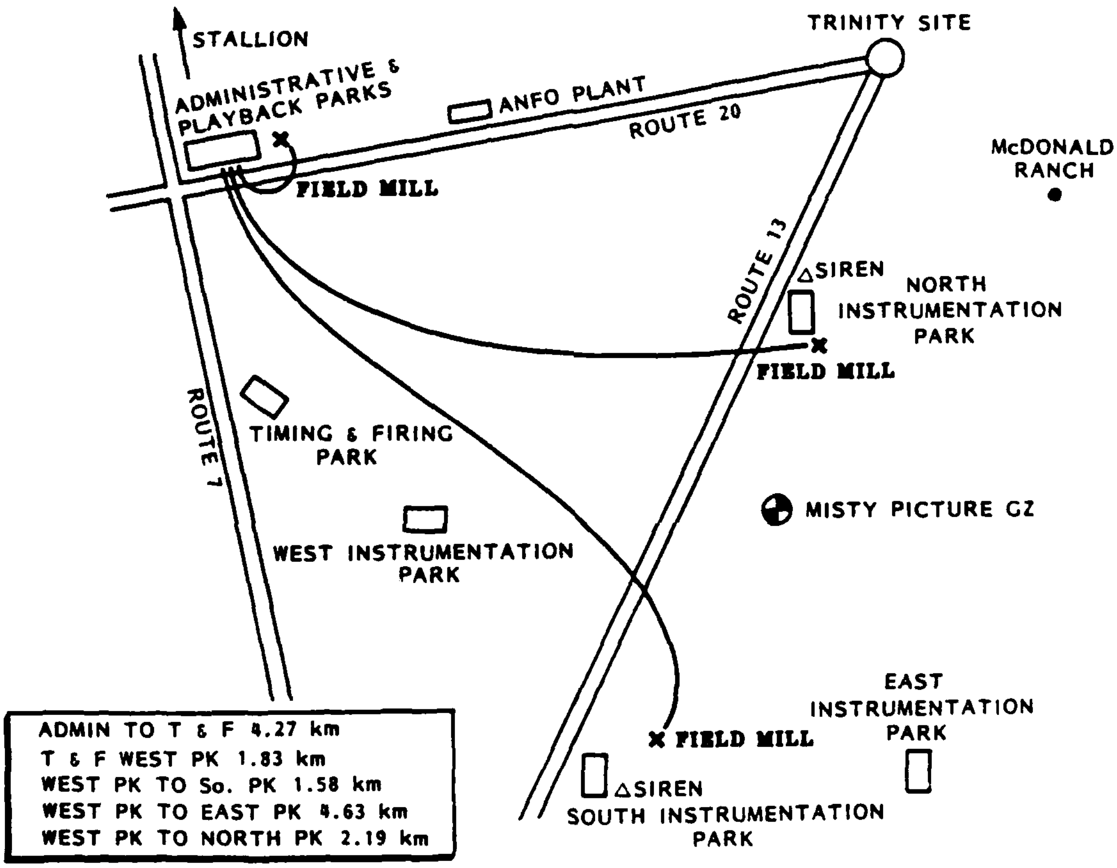


Figure 10. Field mill signal cable layout.

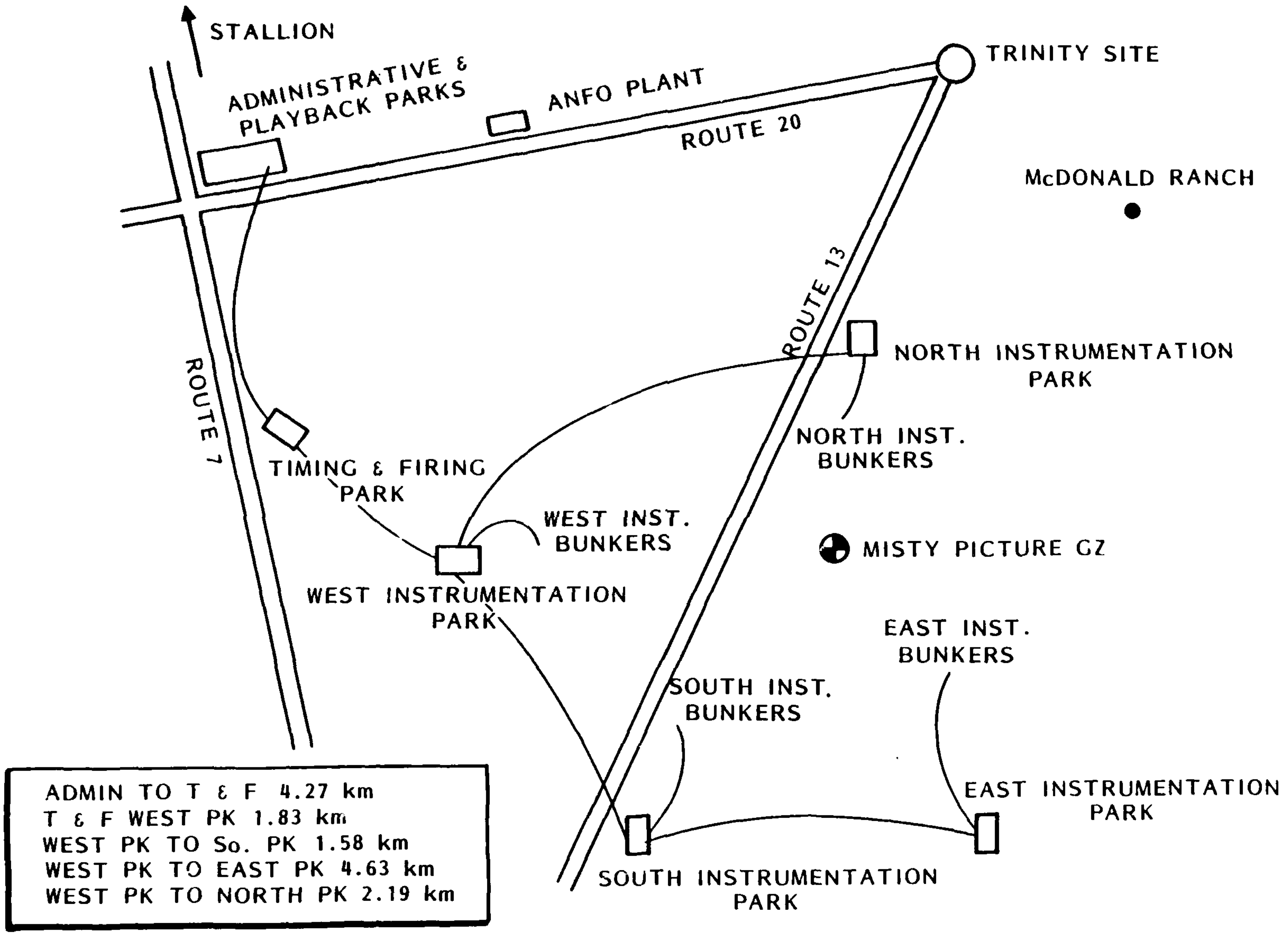


Figure 11. Fiber optic cable layout.

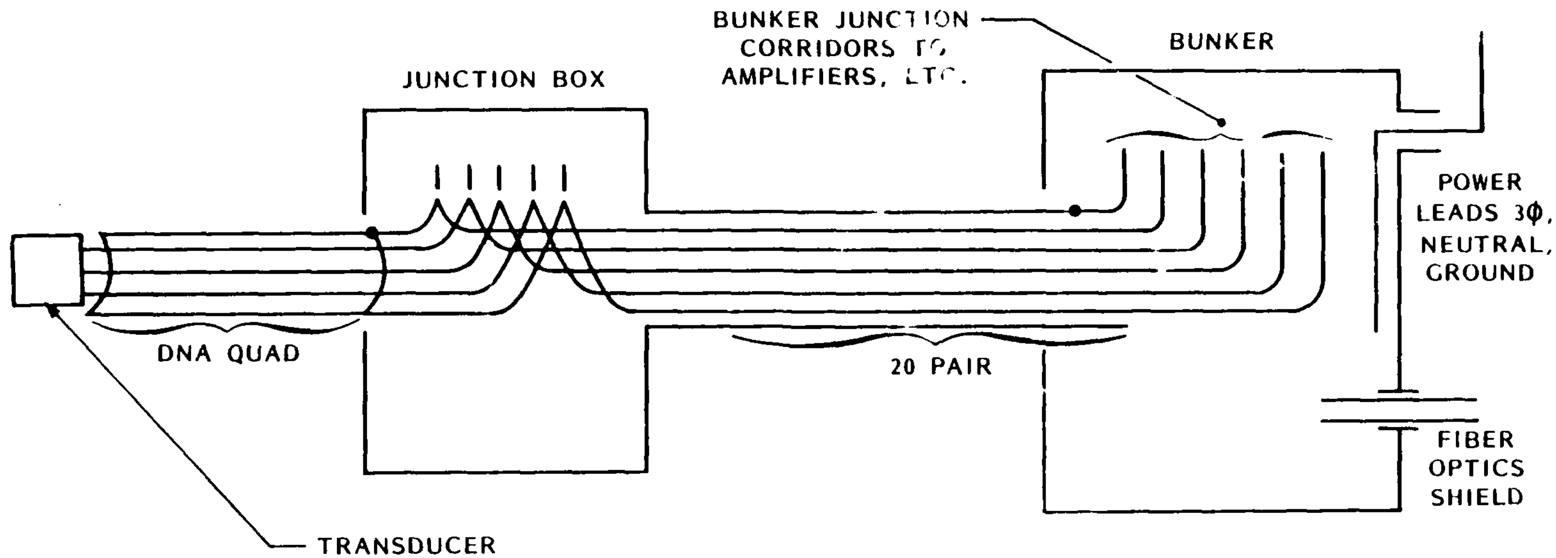


Figure 12. Typical signal path from transducer to instrumentation bunker.

There are connectors on the 20-pair cable side of the junction box that provide circumferential shielding. These cables are often disconnected and replaced with grounding blocks to provide lightning protection. Unfortunately, the grounding block interconnects all of the sensor wires on that junction box to a 90-Ω ground. This interconnection allows catastrophic failure of many of the sensors due to a lightning strike on a single sensor.

As the 20-pair cables continue, the entire cable, including ground wires, enters the bunker, thus defeating the shield there. That shield is further defeated by the power cable, including its neutral and ground wires entry into the bunker. This is shown in Fig. 13. Figure 13 is an example of a particularly bad grounding practice called a shield defeating ground wire. (Ref. 1). This type of wire, shown schematically in Fig. 14a, effectively turns the shield inside out, allowing currents that would flow normally on the exterior of the shield to flow into its interior. This type of wiring, which occurs throughout the test site, should be replaced by the more effective concept of a completely enclosed shield Fig. 14b (Ref. 1).

Another type of protection used at PHETS is the termination of a shield before it enters an electronics box to prevent ground loops. This is not a good practice. Examining the three diagrams in Fig. 15 shows why this is not good practice. In Figure 15a, there is a ground loop formed by the cable shield and ground. However, the currents generated flow only on the shield. The only currents transferred to the loads are those transferred through the cable shield. In Figure 15b, the circumferential bonds have been replaced by pigtails as a labor saving device. There are two circuits in this case (Fig. 15b). The first circuit is the loop formed by the center conductor, two loads and a ground. The second circuit is the shield, the inductors (which are the pigtails), and a ground wire. At early times, the pigtail inductance is large and there is very little current in the shield; it flows in the load circuit. As the load impedance dominates, the current begins to flow in the shield (where it should). In other words, an early time spike is generated in the loads because of the pigtail.

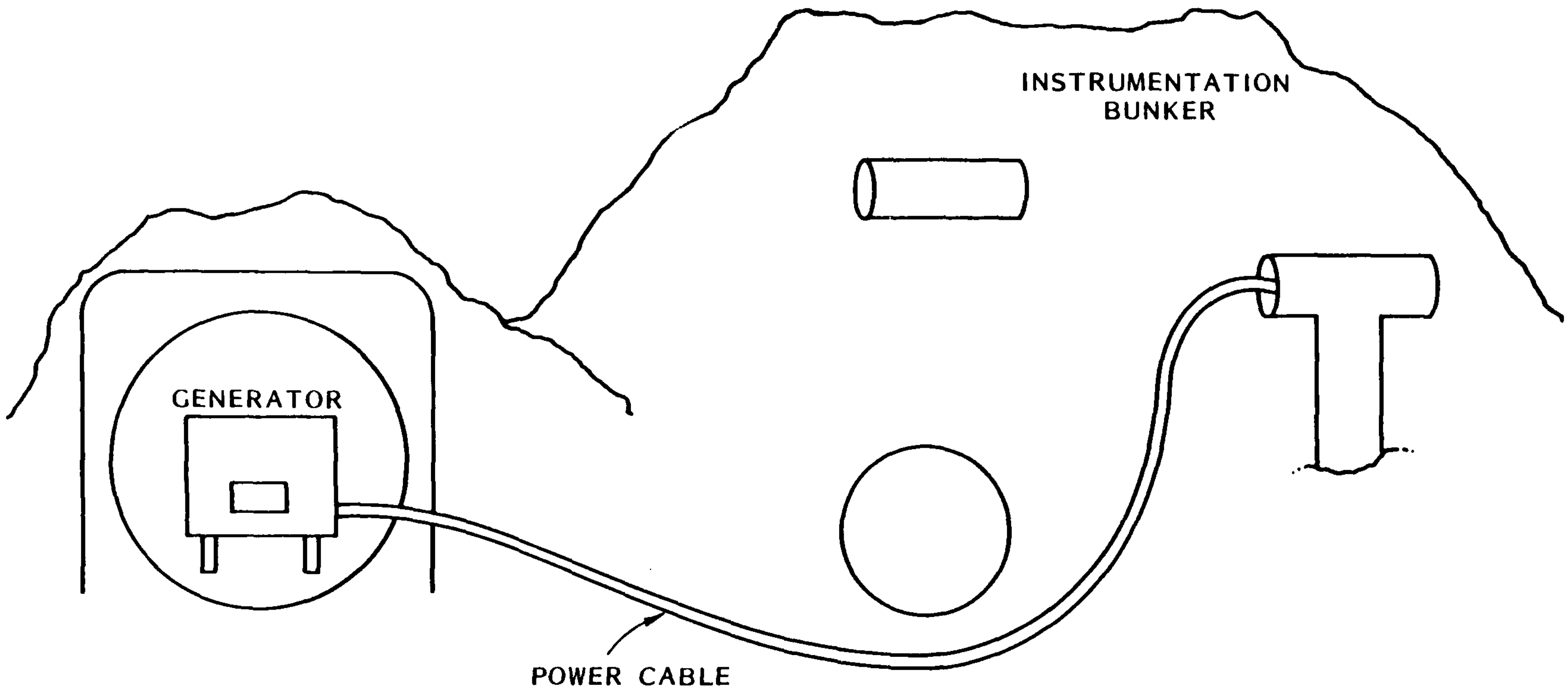
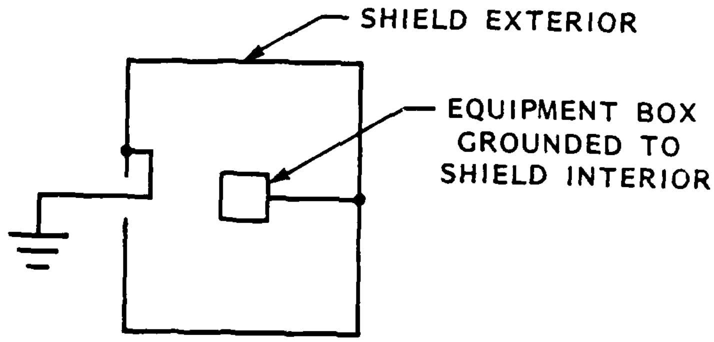
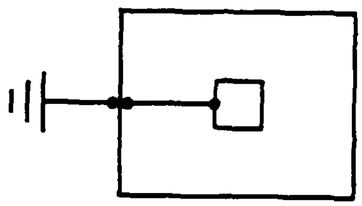


Figure 13. Power cable entering bunker.



(a). Ground wire defeating shield.



(b). Proper installation (shield not broken).

Figure 14. Shield defeating ground wire and properly installed ground wire.

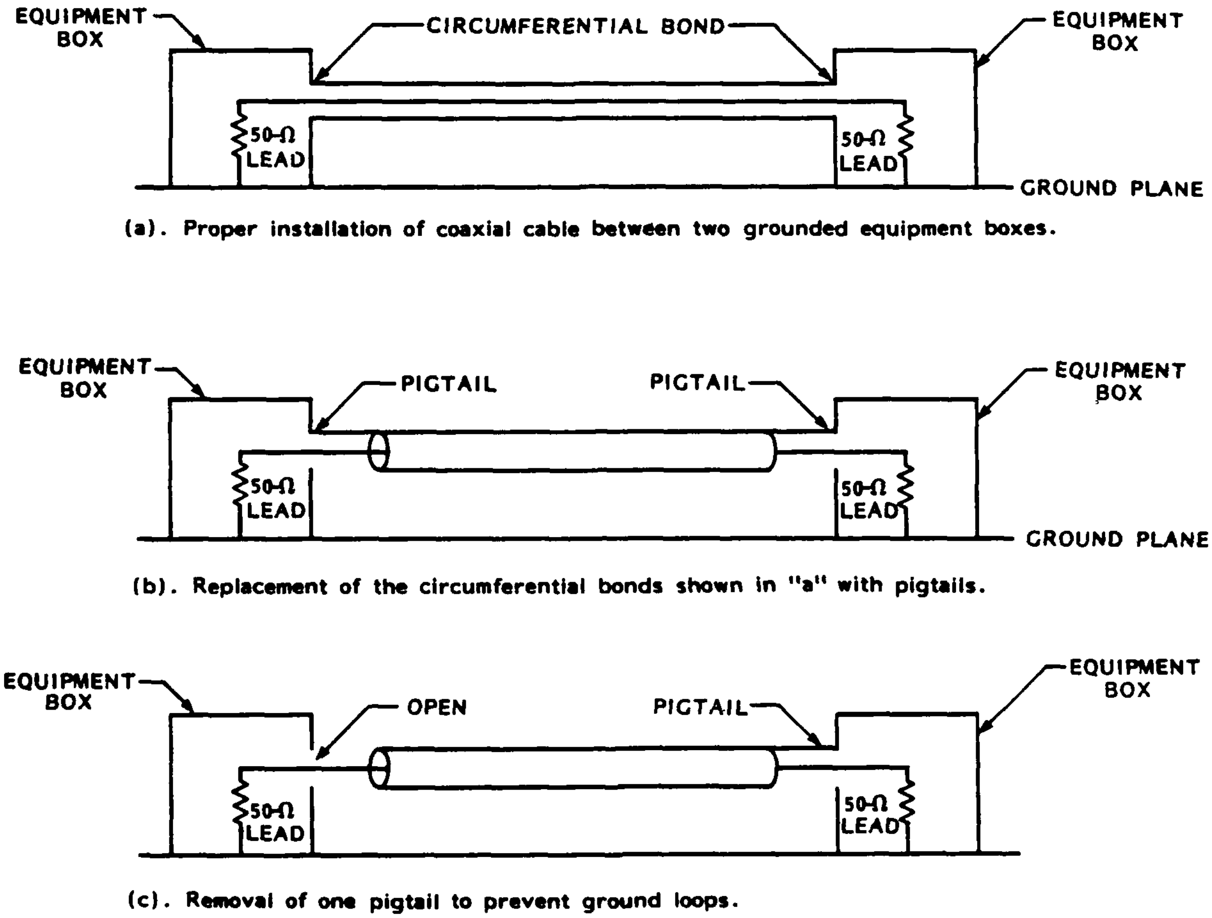


Figure 15. Two equipment boxes connected by coaxial cable by three methods.

Finally, one of the pigtails has been removed, effectively preventing the current to flow from the shield and forcing it into the loads inside the boxes. This configuration effectively defeats the shield. The practice of terminating shields early and leaving the signal wires bare, even for a short distance, should be stopped at PHETS and replaced with a complete, integrated shield.

Finally, there are two large grounding systems within PHETS, the data flow system and the T&F system. These two systems are shown conceptually in Fig. 16. While the intent is to keep these two systems separate, they can be inadvertently combined into one or more kilometer sized loops. This can be done by locally grounding a sensor and by grounding the local T&F signal. If two experimenters do this once there is a problem. If only one experimenter does it once, there is not likely to be a problem because of the large ground impedance. It is recognized that there is an attempt to minimize this problem by using isolation transformers in the T&F system.

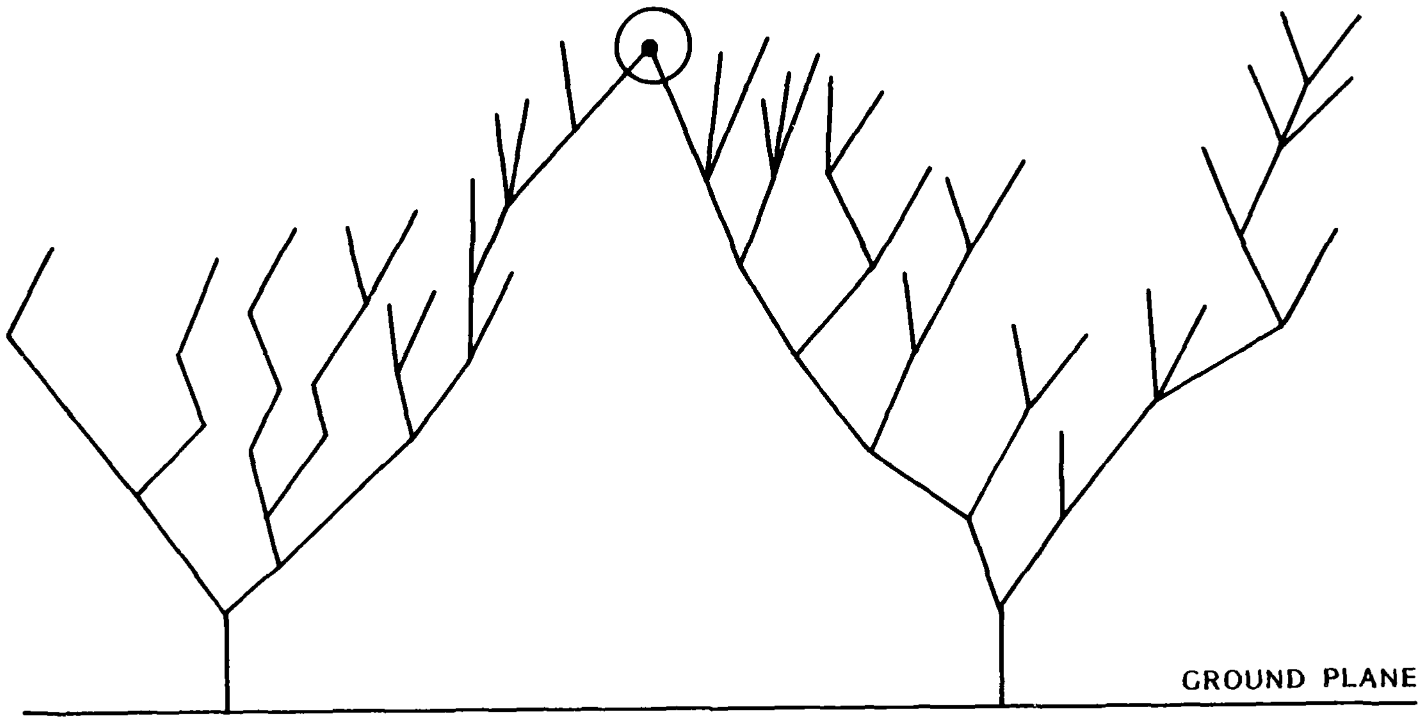


Figure 16. The groundng trees for independent systems showing a large loop when trees are connected.

3.0 EQUIPMENT LIST

3.1 TRANSDUCERS

Transducers or gages are used to sense the physical environment, convert that sense to an electrical signal, and to send that signal to a recording device. There are several types of transducers used at PHETS:

- Pressure gages
- Strain gages
- Stress gages
- Accelerometers
- Velocity gages
- Soil stress gages
- Time-of-arrival (TOA) crystals
- Displacement gages

Nearly all of these transducers use a typical wheatstone bridge circuit (Fig. 17).

3.1.1 Pressure gages--The pressure gages include: bar gages, kulite/endevco gages, the internally strain-gaged(ISG) kilobar stress sensors, and column-based airblast (CBA) gages. The bar gage is useful for pressures at or above 15 k/in^2 (103 MPa). The combined kulite and endevco gages form the kulite/endevco integrated sensor transducer. They are used to measure transient air pressure in the range of 2 to 50,000 lb/in^2 (14 to 345,000 MPa). The ISG is a rugged, low-sensitivity, high-range transducer designed for direct-coupled measurement of shock stresses of 0 to 10 kbars (0 to 1,000 MPa). The CBA operates on the principle of elastic compression of a column and is used to measure airblast pressures of over 87 k/in^2 (600 MPa) in the free field.

3.1.2 Strain gages--The strain gages used are the steel strain gages and the concrete strain gages. Both gages are active gages and are based on

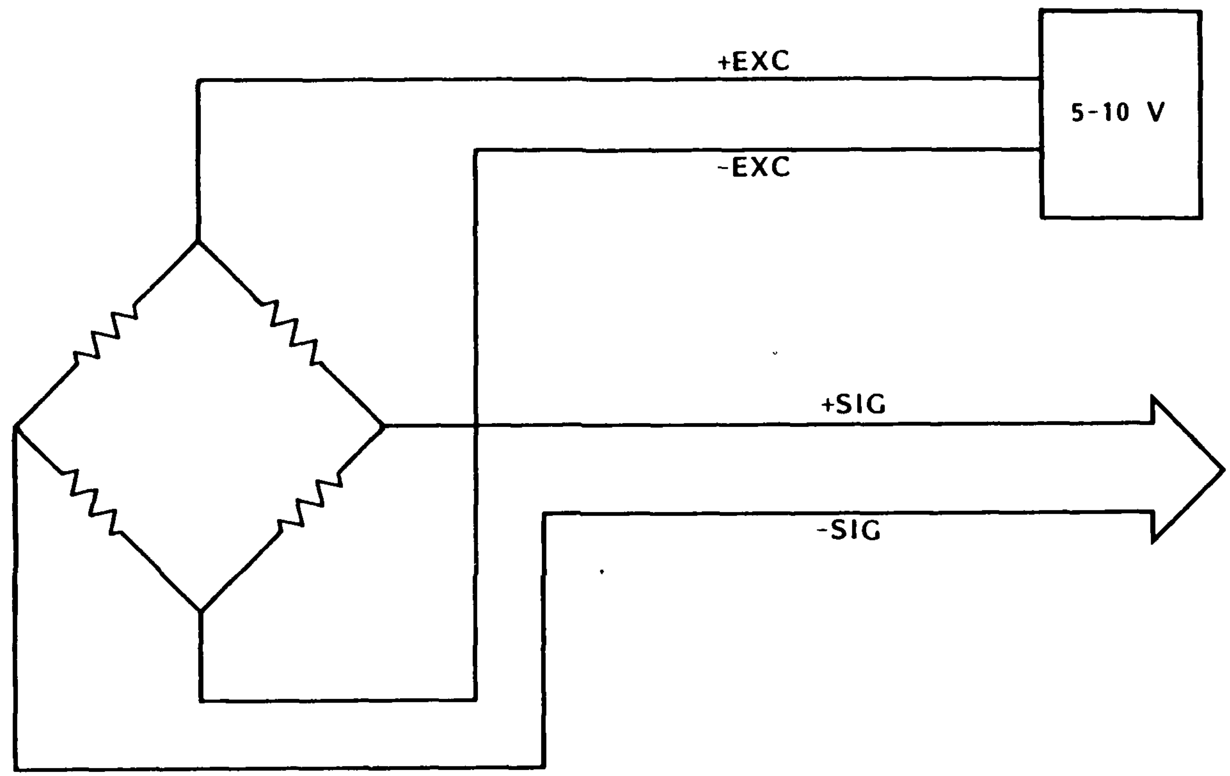


Figure 17. Typical wheatstone bridge circuit.

principle that the resistance of the gage changes in direct proportion to the change in strain level. Steel strain gages are designed for use on reinforcing bars and steel plates. Concrete strain gages may be used to measure strains within concrete members.

3.1.3 Stress gages--The stress gages are: the WAM Gage, the NS Gage, the triaxial interface pressure gage to measure both normal and shear stress. All of these measure normal stress at the structure/soil interface and are embedded in concrete structures. Both WAM and NS gages utilize a strain gage on the sensitive element.

3.1.4 Accelerometers--The Endevco free field or structural accelerometers use an internal strain-gaged sensing element to measure acceleration motions. They are set in epoxy or in aluminum canisters for free-field placement or on mounting blocks for structural measurements.

3.1.5 Velocity gages--The velocity gages include two models of the variable reluctance velocity gage and the mutual inductance particle velocimeter (MIPV) gage. These are variable reluctance, pendulum-type transducers that measure uniaxial velocity from 0 to 1,000 ft/s (0 to 305 m/s).

3.1.6 Soil Stress gages--The soil stress gages include: the low range sensing elements (SE) gage, the high range (HRSE) gage, the column-based soil stress (CBS) gage, and the flatpack gage.

3.1.7 Time-of-arrival crystals--These include piezoelectric crystals which provide shock wave time-of-arrival data. They provide termination voltage to TOADS channels.

3.1.8 Displacement gages--These gages include the linear variable differential transformer (LVDT) and the celesco pull wire gages. The LVDT gages measure linear displacement up to 5 in (127 mm). Typically, this includes relative structural motions and strain measurements in structural members. The celesco pull wire gage is a pull wire potentiometer; i.e. a clock spring-loaded yo-yo with an electrical output. It is used to measure

the linear distance between any points initially separated by more than 6 in (150 mm) and where relative movement includes significant lateral components.

3.2 TRANSMISSION SYSTEM

3.2.1 DNA quad shielded cable --The four-conductor, No. 22 American Wire Gage (AWG), shielded cable was the single most used cable in the MISTY PICTURE test (Fig. 18). During the MP test there were no DNA approved or furnished connectors for this cable. The experimenter provided terminal hardware if it was required. Downstream from the transducer the quad was always attached to a terminal strip either in a junction box or in the instrumentation bunker. See Appendix B for quad detailed specification.

3.2.2 DNA 20-pair shielded cables--The 20-pair, No. 22 AWG shielded cable (Fig. 19) was most often used in the MP test to connect junction boxes to the instrumentation bunker (Fig. 7). When the junction box was not used, the quad cable was run to a terminal strip on the outside wall of the instrumentation container.

3.2.3 Fiber optics cable--A bundle of eight fibers within a steel jacket was used for two-way communication and data delivery between the Playback Park and the instrumentation bunker.

3.2.4 Coaxial cable--The RG-11/U, RG-213, and RG-58/U coaxial cables were used for various subsystems.

3.3 DIESEL GENERATOR

An ONAN (a division of Studebaker) 60 kw, model SF-60-MD/CIED diesel generator provided the needed power. The generator operates either at 120-208 or 240-416 V, 104 or 280 A, and 50-60 Hz.

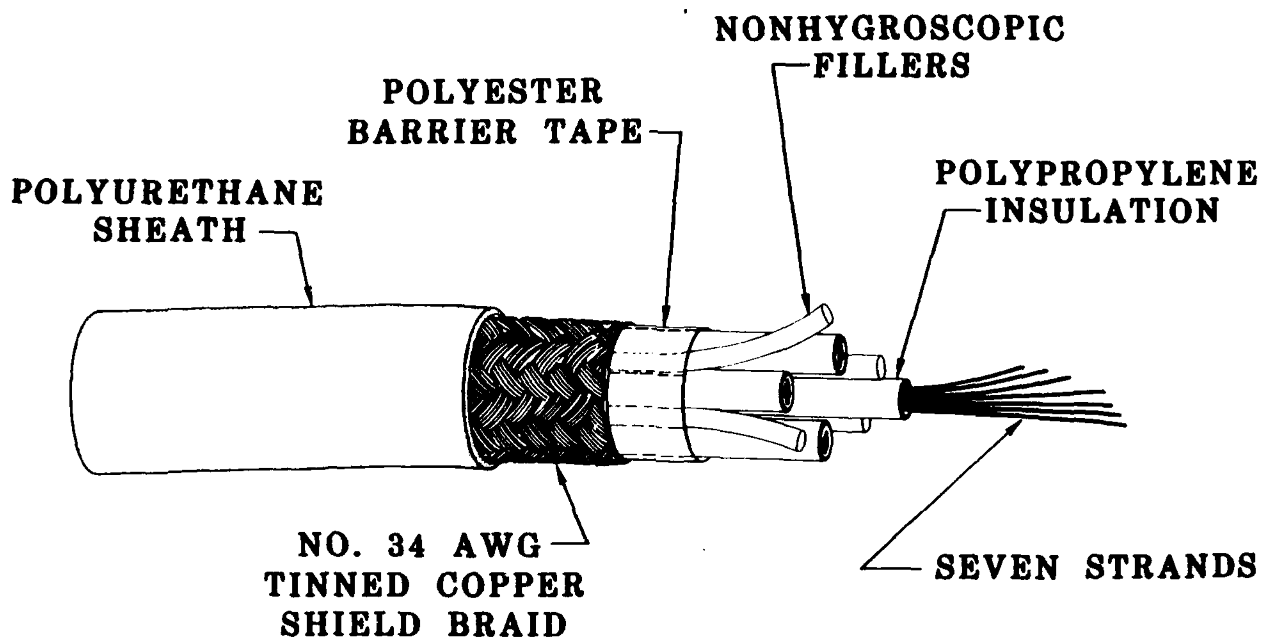


Figure 18. DNA quad cable.

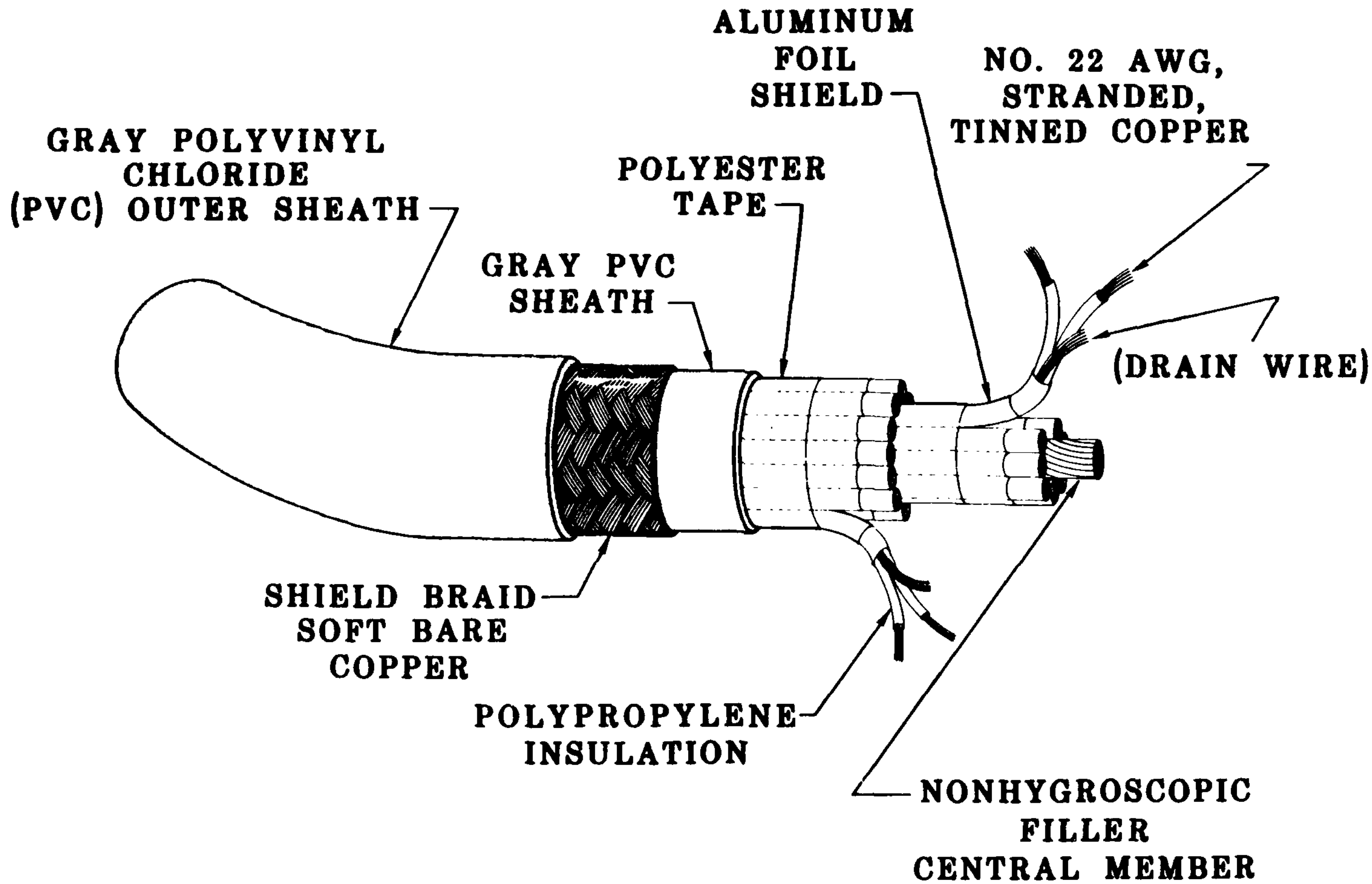


Figure 19. DNA 20-pair cable.

3.4 UNINTERRUPTIBLE POWER SUPPLIES (UPS)

The RTE Deltec 7000 Series uninterruptible power system used in the instrumentation containers consists of a rectifier/battery charger, a DC-to-AC static inverter, a static transfer switch, and a system status display panel. When combined with a battery reservoir, the unit will protect the critical load against power outages and low line voltage for the duration of the battery discharge time. In addition, the UPS provides electrical isolation from the primary AC source to help reduce the effects of electrical noise.

The Powerbase 1000 built by Solidstate Controls, Inc., is a 3.0 kVA, 3-phase uninterruptible power system used at the Playback park. The system contains a rectifier, static inverter, battery charger and batteries. It conditions the quality of AC power to the equipment, thus protecting against line voltage and frequency problems. Upon power failure or transient, the batteries supply DC power to the inverter and the inverter converts this DC power to AC power. This sequence occurs without any power interruption to protected equipment and will continue until utility power is restored or until the protected batteries are exhausted (15 min of battery life is available at full load).

3.5 INSTRUMENTATION AMPLIFIERS

The Pacific Instruments, Incorporated Model 8656 transducer conditioning amplifier is installed in-line in data channels entering the instrumentation containers. The Model 8658 signal conditioning amplifier provides excitation, conditioning, balance, calibration, amplification, and filtering for strain gages and one, two, or four arm resistive transducers. The model 8658 is also useful with potentiometric transducers, thermocouples, and other low level signal sources. Each channel is a plug-in module with front panel controls for gain, balance, and excitation. Monitor jacks are installed for measuring amplifier output and excitation. A light emitting diode (LED) indicator allows transducer balance without external instrumentation.

The Ectron Model 753A signal conditioner/amplifier is an AC line powered plug-in unit containing a high performance differential DC amplifier, active filter, and signal conditioning functions which include constant voltage or constant current transducer excitation, and balance and calibration with a front panel plug-in conditioner subassembly. All modules install from the front of the enclosure. Each channel is configurable to changing input requirements; one, two, and four arm bridge circuits, as well as potentiometers. This model has individually isolated, regulated and adjustable constant voltage/constant current transducer excitation. On the front panel are mounted monitor jacks for excitation and amplifier output. Bridge completion, balance and calibration resistors are mounted on a separate front panel removable plug-in subassembly. The Model 753A was specifically designed to accurately process low level signals in electrically noisy environments by providing excellent common mode rejection and EMI immunity.

3.6 TRANSIENT DATA RECORDER

The Pacific Instruments, Incorporated Model 9822-2189 transient data recorder is designed to condition, sample, digitize and store in nonvolatile complementary metal-oxide semiconductor (CMOS) memory, high-speed analog data. Data acquisition, recording and playback control functions are bus-structured for direct interface to a digital computer. Ten channels mount in a 7-in high rack enclosure which is line-powered and includes interface logic. The TDR consists of a sample-and-hold amplifier, 12 bit analog-to digital converter, control logic and 64K words of CMOS memory (memory is expandable to 128K). It digitizes an analog signal at a programmed sample rate and stores each sample in successive locations in memory. The memory includes battery back-up to retain data in the event of power loss.

4.0 RECOMMENDATIONS

A lightning protection system can be designed to protect against a direct strike and/or against effects or currents induced in the system by the fields produced by a nearby lightning strike. Complete protection against direct strikes requires enclosing the total test area in a conductive enclosure or Faraday cage. This is impossible for the overall PHETS area. For volumes of much smaller size, special penetration protection is required. For example, power filters for the electrical power penetrations of the instrumentation bunkers.

Therefore, the feasible protection system for PHETS should protect items of high value from direct strikes by diverting the surge current away from the high value items (including personnel) to earth ground and by shielding nearby items from transients. This type of protection should be provided for all of the parks, the explosive container, the instrumentation bunkers, the transducers (to the extent possible), and the interconnecting cabling.

When the explosive is in place; i.e., as soon as the ammonium nitrate and fuel oil (ANFO) is being mixed and delivered to the ground zero container, personnel should be evacuated to safe areas during potentially hazardous conditions. The field mill system and visual observation are essential in making the evacuation decision.

The instrumentation system consists of essentially three parts: (1) sensors/transducers which produce the desired electronic signals, (2) the digitizing/recording instrumentation, and (3) the interconnecting cables. The following are some considerations when designing a lightning protection scheme.

Conducting loops must be avoided, since magnetic induction will cause currents to flow through such loops. Ideally, all parts of the system should be designed so there are no potential differences which could cause arcing. This is practically impossible for the PHETS because of the long

cable runs between instruments, but there are good engineering practices and designs which can reduce vulnerability. The use of voltage limiting devices will limit transients to harmless levels.

The bermed instrumentation bunkers containing the instrumentation containers are ideally designed for protecting personnel but, because of the various conductive penetrations, are not sufficiently protective of the instrumentation (Ref. 2). Obvious efforts have been made to enhance the bunkers' protective design by using waveguides for instrumentation cabling coming into the bunkers and minimizing air flow and personnel openings. Fortunately, much of this is done to protect against blast but has the synergistic effect of improving the Faraday cage effect.

To utilize the advantage of the waveguides it will be necessary to circumferentially bond the incoming data cable shields to the waveguide. A point of interest here is the practice of using the quad cable shield for the guard into the amplifiers and, hence, negating the ability to use the shield for lightning protection. The use of a five conductor cable in place of the quad is a possible solution to this problem. An alternative is to filter each signal wire at its point of entry into the bunker and to provide electrical surge arresters. Additionally, the electrical power line should be filtered at its point of entry into the bunker and electrical surge arresters should be provided. If this is done, then all of the protection for the diesel generator will be against blast and shock only since the incoming power line will be no different (electrically) than a commercial power source. Once these practices are put in place, it is essential they not be circumvented by unprotected penetrations, such as, unfiltered radio and telephone lines.

For the instrumentation parks, the current practice of using isolation transformers and motor generators for utility and instrumentation power is satisfactory. The shortcoming at the instrumentation parks is the use of unconditioned power for trailers and other nontest related items, i.e., those items used in preparation for the test but removed or disconnected prior to the test. These items should have individual circuit protection to prevent damage during the pretest period.

4.1 SPECIFIC EXAMPLES

4.1.1 Commercial Power Conditioning--There were several incidents of lightning induced transients coming through the commercial power system. These transients damaged individual microcomputers, a weather video monitor, telephones, the Field Mill sensor units, the Field Mill monitor/relay /computer system, and possibly other unreported equipment. The Field Mill system was modified to include power conditioning and surge arresters. This corrective action was taken two weeks prior to the MISTY PICTURE test, and no more problems occurred.

All equipment using raw commercial power should be protected by surge arresters. This includes all experiments and experimenters using computers, data reduction systems, test equipment, etc., anywhere on the test site. This is especially applicable to the Administrative Park where all experimenters have assigned space. The preferred solution is that all of the power used in the Administrative Park be conditioned power. The telephone system should have appropriate surge protection.

4.1.2 ANFO Charge Container--The charge container for MISTY PICUTRE was protected by a lightning protection system. This system was madeup of a top-mounted lightning arrester connected to 12 down conductors which, in turn, were connected to a counterpoise laidout circumferentially around the base of the hemispheric charge container and attached to 12 equally spaced, 8-ft-long earth ground rods.

Good practice requires that the earth ground rods, counterpoise, and down conductors be placed at least 6 ft from the protected item, (Ref. 3). In this case, it should be at least 6 ft from the charge container's outer wall. This distance was experimentally arrived at to minimize the chance of arcing from the grounding system to some conductor on the container wall or inside the container. Upon observation of the ANFO filling procedure, it appeared the trucks were able to stand-off more than 6 ft during the loading process.

There were three systems installed on or in the charge container that caused concern. The most worrisome of these was the detonation cord (detcord) that ran from the booster at the center-base of the hemisphere to the outer wall of the container. Four detcords were spaced equally around the circumference of the hemisphere. For mechanical protection each of the four detcords had an aluminum shield. Prior to filling the container with explosive, the four detcords were put in place with several feet of the detcord coiled and taped to the container's outer wall.

The TOADS system was a second cause of concern. This system requires an array of wires imbedded within the ANFO mixture and has piezoelectric crystals spaced along the wires. This system is not directly wired to the booster, but comes very close to the booster.

The third system of concern was the stress/strain gages installed on the wall of the charge container. This system was used to measure the pressures on the container wall by the ANFO and is probably the least dangerous of the three concerns.

A nonconducting detcord should be used. Wherever any conductor penetrates the container wall, there should be a down-conductor screen that directs any lightning caused current to earth ground with minimum surge impedance/potential buildup.

4.2 INSTRUMENTATION BUNKER/INSTRUMENTATION CONTAINER

The existing installed configuration provides a large conducting shield with waveguide tubes for the signal line entry, personnel entry and pressurization equalization (Figs. 3 and 13). The lower ventilation pipe is also designed as a waveguide, but its purpose as a waveguide is defeated by the diesel generator power line passing through it (Fig. 13). The upper ventilation pipe is of much shorter length, but it is estimated that it provides a satisfactory waveguide cutoff.

The shield topology should be completed by terminating ground wires on the outside of the bunker, the closing of unnecessary penetrations, and the use of filters. The power cable should be brought into the bunker through a power filter and this should eliminate the noise now transmitted to the instrumentation container. (The instrumentation container is used for environmental control and provides no electrical isolation as it is grounded at four places to the bunker.) This would then permit proper grounding of the instrumentation to the interior of the bunker to eliminate shock hazards.

4.3 JUNCTION BOXES

The junction-box (J-Box) design contributes to noise and lightning susceptibility. The J-Boxes should be designed so they are Faraday cages and provide a shunt for currents on cable shields around the interior of the J-Box. Circumferential grounding at the box should be used to maintain shield integrity and no ground wires should be allowed to penetrate the J-Box. Surge protection could be included in the J-Boxes to protect sensors. The ideal location for surge protection is nearer the sensor than several hundreds of feet away at the J-box location, but with the J-Box under Field Command control, the capability to protect all but the sensor that is struck is much greater. Also, this allows a more compact design for the protective equipment.

4.4 SHORTING BLOCKS

Shorting blocks have been used for lightning protection, but they have the disadvantage of coupling the transients from one or a few sensors to all other sensors sharing the same shorting block. This probably will occur because the typical earth ground using an 8-ft-long grounding rod has approximately 90-Ω resistance and the threat level currents are not shorted to ground as intended. Until now, the best protection has been simply to disconnect the sensor when there is a lightning threat or when no work is being performed. This technique certinly works in most instances but is labor intensive and time critical.

The disconnect process certainly does protect the sensor but is of little use if the sensor is buried or is hardwired to the J-Box or even to the instrumentation bunker as is often the case within 10 days to 2 weeks prior to the test date. Also, even if the sensors are able to be disconnected, there may be more than can be reasonably disconnected in the warning time allowed for a fast moving thunderstorm.

The best solution is the appropriately designed J-Box coupled with appropriate transient protection which will eliminate the need for the disconnects. This will be to the advantage of the experimenters since they will have much less handling of the sensor wiring causing broken wires and connectors and sometimes safety problems.

The shorting block's best use is to discharge static buildup on cables that have not been used for several hours, e.g., overnight.

4.5 GENERIC TOPOLOGY

The most important recommendation for the grounding and shielding effort is that of maintaining a layered topology approach to shielding. This is more important then transient protection, but both may be included to enhance lighining protection. Figure 20 shows a hardened equivalent of the the sensor to bunker topology diagram in Fig. 12. As noted, the entire exterior is a continuous shield, except for particular penetrations. Small openings in the bunker will not cause difficulty if there are no cables running through them.

The first opening is at the transducer itself. The shield is not connected to the sensor at this point. Transient protection is recommended as near the sensor as possible. In this version of the hardened system an additional wire has been added to the quad, making it a five conductor shielded cable. The reason for the additional wire is to provide an additional reference or neutral wire for the amplifiers. Since this wire is apparently required inside the bunker, it must be treated as a signal wire, not a shield as has been done in the past.

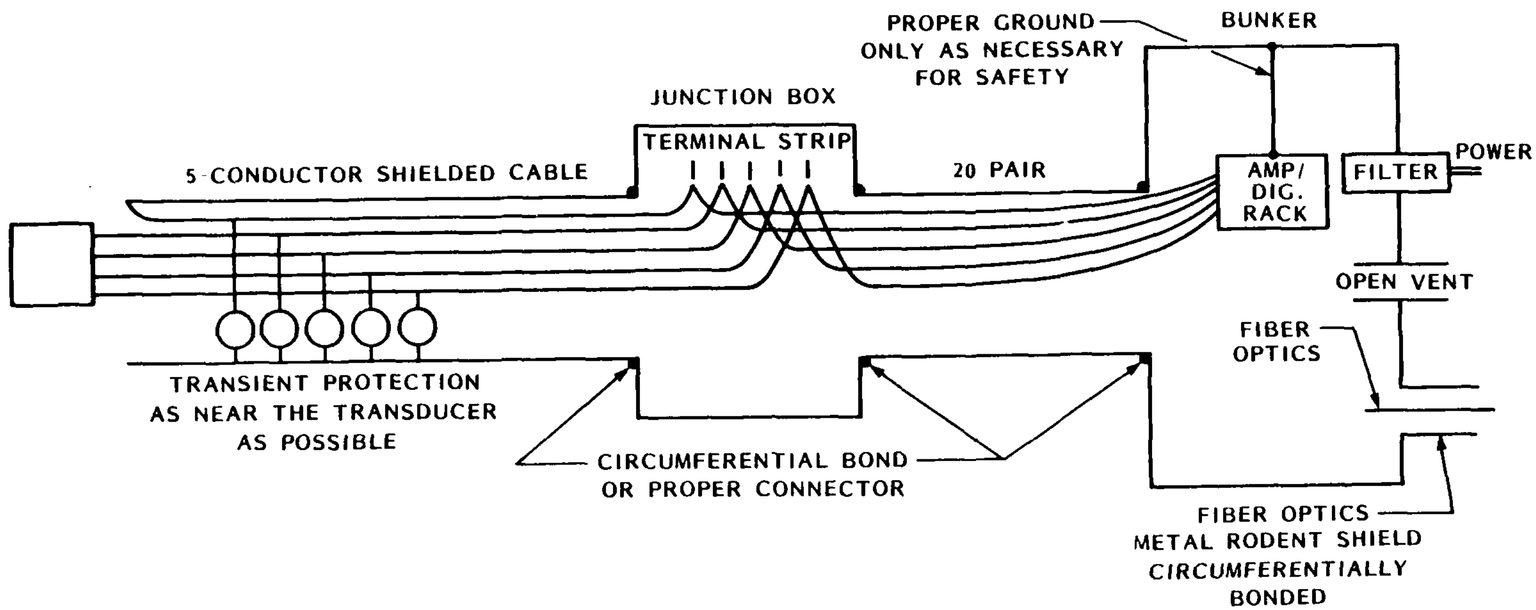


Figure 20. A hardened analogue to Figure 12.

The junction box becomes a completely sealed system rather than the open structure it is now. Designs have been examined by MRC for junction boxes with varying degrees of transient protection built into the junction box. How much of this is necessary can only be determined by testing.

The 20-pair cables are now complete cables with connectors on both ends. The shield is then properly connected to the bunker and junction box. Note that this configuration is similar to Fig. 20. Loops should be minimized by tying bundles together to minimize field coupling and overhead ground wires should be used to protect cables from direct strikes. This last can be shown in Fig. 21, and is used by power companies and the New Mexico Institute of Mining and Technology at their lightning facility to protect from direct strikes.

The bunker itself is also hardened to prevent noise or large currents from entering. The power cable now enters through a commercial power filter, rather than entering through the vent. Nothing now blocks the vent. Fiber optic cable shields are terminated the same way as cable shields. In particular, cable shields remain integral with the exterior shield as they should.

Mission Research Corporation recommends that a complete hardened system be constructed in prototype form and in accordance with these practices. It may be most efficient to do this in concert with the Precision Test Bed, but the prototype should be as complete as possible, including hardening the bunker. Complete current injection testing must be accomplished to assure some coupling mode has not been overlooked.

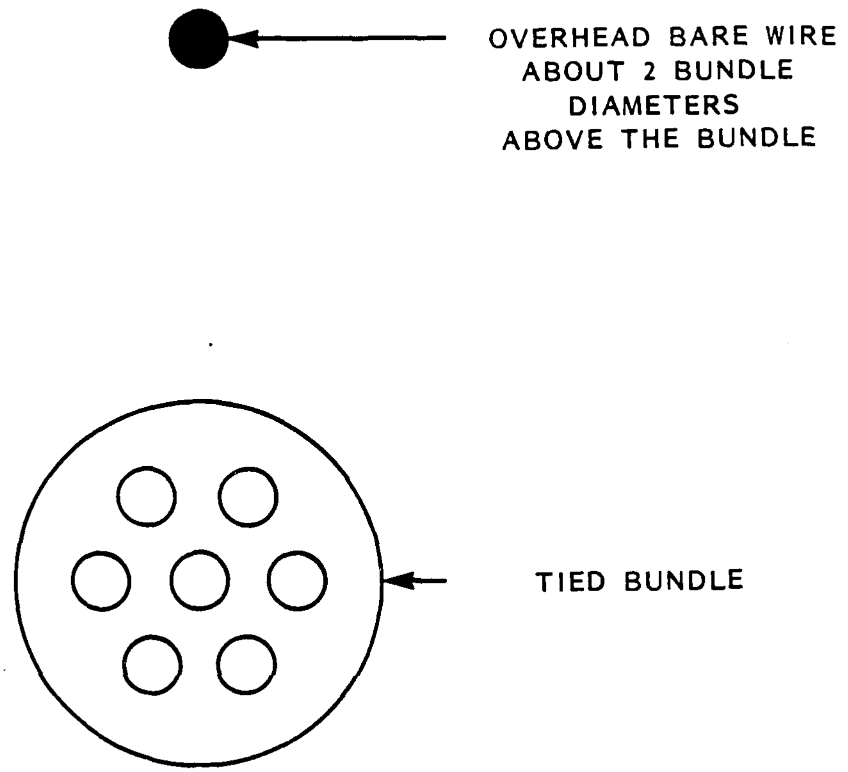


Figure 21. Wire bundle protected by overhead ground wire.

5.0 CONCLUSIONS

Personnel safety is paramount and above all other concerns. In the past no personnel have been injured by lightning caused effects, but one time is too many. To this end the greatest potential for widespread injury and damage lies with the explosive container. Proper grounding with minimum standoff distances to prevent arching have been presented in this report and previous reports. Also, recommendations have been made to reduce the danger by using less conductive or nonconductive detcord shielding.

For all other areas of concern to personnel and equipment safety, the field mill system correlated with visual observations is an excellent way to give warning to personnel. The personnel take any preplanned equipment protection action and then evacuate the danger zone.

For facilities such as the Administrative Park, Playback Park, T&F Park, etc., personnel safety is best served by an overhead matrix of conductive wires. This technique is especially protective to individuals in the open between trailers.

For equipment protection in the trailer areas, it is necessary to protect against conductive transients. This type of protection is done with various surge and shunting schemes/hardware as presented in this report and in the references. Items to be protected include: microcomputers, telephones, support hardware, etc. This type of protection is essential to equipments connected to the commercial power system.

A facsimile of the data system starting with the sensor and flowing back to the instrumentation containers should be tested in the precision testbed. Additionally, some direct injection testing of the cables, junction boxes, ports-of-entry, etc. should be done, and the instrumentation bunker shielding should be tested (with penetrations installed) to determine what frequencies are attenuated and to what magnitude they are attenuated.

The ultimate protection of equipment and personnel within, where applicable, is the Faraday cage topology referred to and described in this report. Where this concept is not reasonable then techniques such as disconnecting various sections of the system during threat periods, the use of overhead neutrals, the use transient overflow devices, avoiding conductive loops and inductive alignments, etc. must be practiced.

Finally, all personnel must be informed and trained to follow proper procedures and to recognize the compromising designs and situations to be avoided.

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DEFINITIONS

Berm--earthen buildup, usually above grade, around a man-made structure.

Booster--an assembly of metal parts and explosive charge provided to augment the explosive component of a fuse, to cause detonation of the main explosive charge of the munition.

Channel--a path along which digital or analog information may flow. A channel may be single (simplex) or multiplexed (allowing concurrent transmission of more than one information stream on a single channel).

Characteristic Impedance (Surge Impedance)--the impedance that, when connected to the output terminals of a transmission line of any length, makes the line appear to be infinitely long, for there are then no standing waves on the line, and the ratio of voltage to current is the same for each point on the line.

Conductor--a wire, cable, or other body; or medium that is suitable for carrying electric current. Conductors may be signal-carrying or excitation carrying.

Detonator--a device, such as a percussion/blasting cap employing a sensitive primary explosive, used to detonate a high-explosive charge.

Digitize--to convert an analog measure of a quantity into a numerical value.

Drain--metallic conductor frequently used in contact with foil-type, signal-cable shielding to provide a low-resistance ground return at any point along the shield.

Faraday Cage--a closed, or nearly closed hollow conductor (can be very large or very small), usually grounded, within which apparatus is placed to shield it from electrical fields.

Fiducial Time--time of detonation.

Filter (Electric Filter; Electric Wave Filter)--any transmission network used in electrical systems for the selective enhancement of a given class of input signals; a network that transmits alternating currents of desired frequencies while substantially attenuating all other frequencies.

Free Field--a field in empty space not interacting with other fields or sources.

Fuse--a device with explosive components designed to initiate a train of fire or detonation in an item of ammunition by an action such as hydrostatic pressure, electrical energy, chemical energy, impact, or a combination of these.

Gas Tube--an electron tube into which a small amount of gas of vapor is admitted after the tube has been evacuated; ionization of gas molecules during operation greatly increases current flow.

Grounding--intentional electrical connection to a reference conduction plane, which may be the earth, or may be a specific array of interconnected electrical conductors referred to as the grounding conductor.

IRIG--Inter-Range Instrumentation Group, absolute time supplied to any node requiring such.

Isolation Transformer--a transformer inserted in a system to separate one seciton of the system from undesired influences of other sections.

Lead--a wire used to connect two points in a circuit.

Lightning Protection--means, such as lightning rods and lightning arresters, of protecting electrical systems, buildings, and other property from lightning.

Motor-Generator Set--a motor and one or more generators that are coupled mechanically for use in changing one power-source voltage to other desired voltages or frequencies.

Piezoelectric--having the ability to generate a voltage when mechanical force is applied, or to produce a mechanical force when a voltage is applied.

Signal Conditioner--unit to process the form or mode of a signal to make it intelligible to or compatible with a given device, such as a data transmission line. Signal conditioning manipulations include pulse shaping, pulse clipping, digitizing, and linearizing.

Standing Wave (Stationary Wave)--a wave in which the ratio of an instantaneous value at one point to that at any other point does not vary with time.

Standing Wave Ratio--any transmission line such as a waveguide or an acoustic transmission system, unless terminated by its characteristic impedance, will exhibit a superposition of standing and progressive waves. The standing-wave ratio is a measure of the relative amplitudes of the two types of wave and is defined as the ratio of the maximum amplitude of pressure (or voltage) to the minimum amplitude of pressure (or voltage) measured along the path of the waves. Thus, at a given frequency in a uniform waveguide the standing-wave ratio is the ratio of the maximum to the minimum (or inverse) amplitudes of corresponding components of the field (or the voltage or current) along the waveguide in the direction of propagation.

Surge Arrester (Lightning Arrester)--a protective device designed primarily for connection between a conductor of an electrical system and ground to limit the magnitude of transient overvoltages on equipment.

Surge Suppressor--a circuit that responds to the rate of change of a current or voltage to prevent a rise above a predetermined value; it may include resistors, capacitors, coils, gas tubes, and semiconducting disks.

Transducer--any device or element which converts an input signal into an output signal of a different form.

Transient--a pulse, damped oscillation, or other temporary phenomenon occurring in a system prior to reaching steady-state condition.

TPD--Transient Protection Device.

Transient Response--behavior of system following a sudden change in its input.

Uninterruptible Power Supply (UPS)--incorporates complex equipment that must be planned and specified carefully before purchase. These systems, consisting of solid-state rectifier-inverters (often backed up by engine-generators), are used to supply power to computers, on-line data processors, process controllers, and other critical loads, to prevent costly power interruptions. The heart of the UPS is the rectifier-inverter unit, or module, which accepts ac line power and delivers transient-free ac power to the critical load. A battery supplies power, for up to several minutes, to the inverter when the ac line power source is interrupted. Rectifier inverter units are employed in many combinations to supply a critical load--singly, in parallel, with a bypass switch, backed up by engine-generator sets, etc. The particular combination selected is determined by the magnitude of the critical load power, the pattern of anticipated ac line interruption, and the sensitivity and critical nature of the load.

Wheatstone Bridge--a four-arm bridge circuit, all arms of which are predominantly resistive; it is used to measure the electrical resistance of an unknown resistor by comparing it with a known standard resistance.

Zener Breakdown (Zener Effect)--nondestructive breakdown in a semiconductor, occurring when the electric field across the barrier region becomes high enough to produce a form of field emission that suddenly increases the number of carriers in this region.

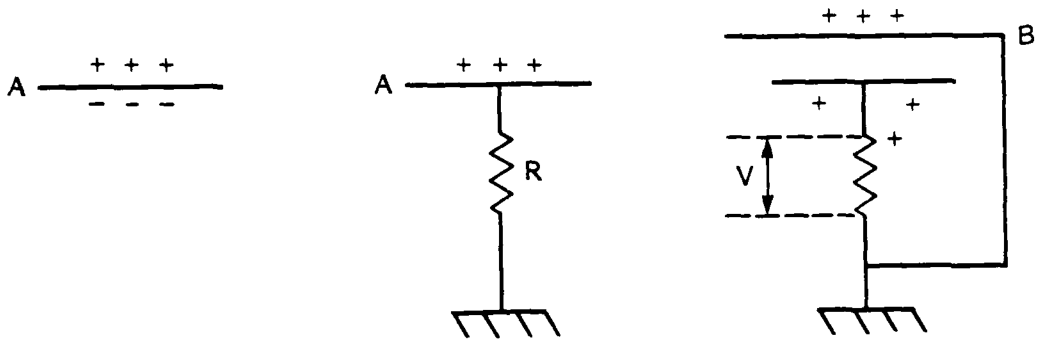
Zener Diode--a semiconductor breakdown diode, usually constructed of silicon, in which reverse-voltage breakdown is based on the Zener effect.

APPENDIX A

FIELD MILL SYSTEM

A-1. THEORY OF OPERATION

Consider the effect of an electric field, whether it be the fine-weather field or the field due to a thundercloud, on a horizontal metal plate A exposed to the field. Charges of equal magnitude but of opposite sign are induced on the upper and lower surfaces of the plate (Fig A1-a). When the plate is connected to earth (Fig. A1-b) through a resistance R the lower charge will flow to ground while the upper charge remains on the plate since it is bound by the electric field.



a. Charged plate. b. Grounded charged plate. c. Two grounded plates.

Figure A-1. Field Mill theory.

Now move a second plate B, which is earthed (Fig. A-1c) over the top of the original plate but without touching plate A. Plate B screens A from the lines of force, so the charge on the latter is no longer bound and starts flowing to earth through the resistance R. A potential difference V is produced across R. When plate B is rapidly moved back and forth above plate A, so as to shield and uncover it alternately, an alternating potential whose amplitude is proportional to the field intensity will be generated across R.

Field mills use the above principles for measuring electrostatic fields. The screening plates are, however, not moved manually, but are motor driven and consist of vaned discs which on rotation alternately screen and open the detecting electrodes. The alternating voltage V generated across R is approximately sinusoidal. This waveform is amplified and recorded and may then be printed. A printed record is shown in Fig. A-2 (Typical Field Mill Chart).

The PHETS field mill monitoring system consists of a signal monitoring box and a Hewlett Packard think jet printer. The signal monitoring box (Fig. A-3) is connected to the analog outputs of three E-100 field mills (Fig. A-4, field mill topography and Fig. A-5, field mill installation). The box has terminals for three relay closures which can be connected to automatically turn on sirens or other remote warning devices. There is an override switch on the front panel so this automatic feature can be disabled. When the override switch is down the relays will be open regardless of the atmospheric electric field strength. When the override switch is up the relays will close when the fields exceed 1500 V/m.

The signal monitoring box display consists of three indicator lights - green, amber and red. When the atmospheric electric fields at all of the mills are below 500 V/m, the green light will be on. When the field at any mill is between 500 V/m and 1500 V/m, the yellow light will go on and the printer will start printing. When the field at any mill is between 1500 V/m and 2500 V/m, the red light will come, the printer will continue printing, and an audible alarm will sound once a minute. At this level,

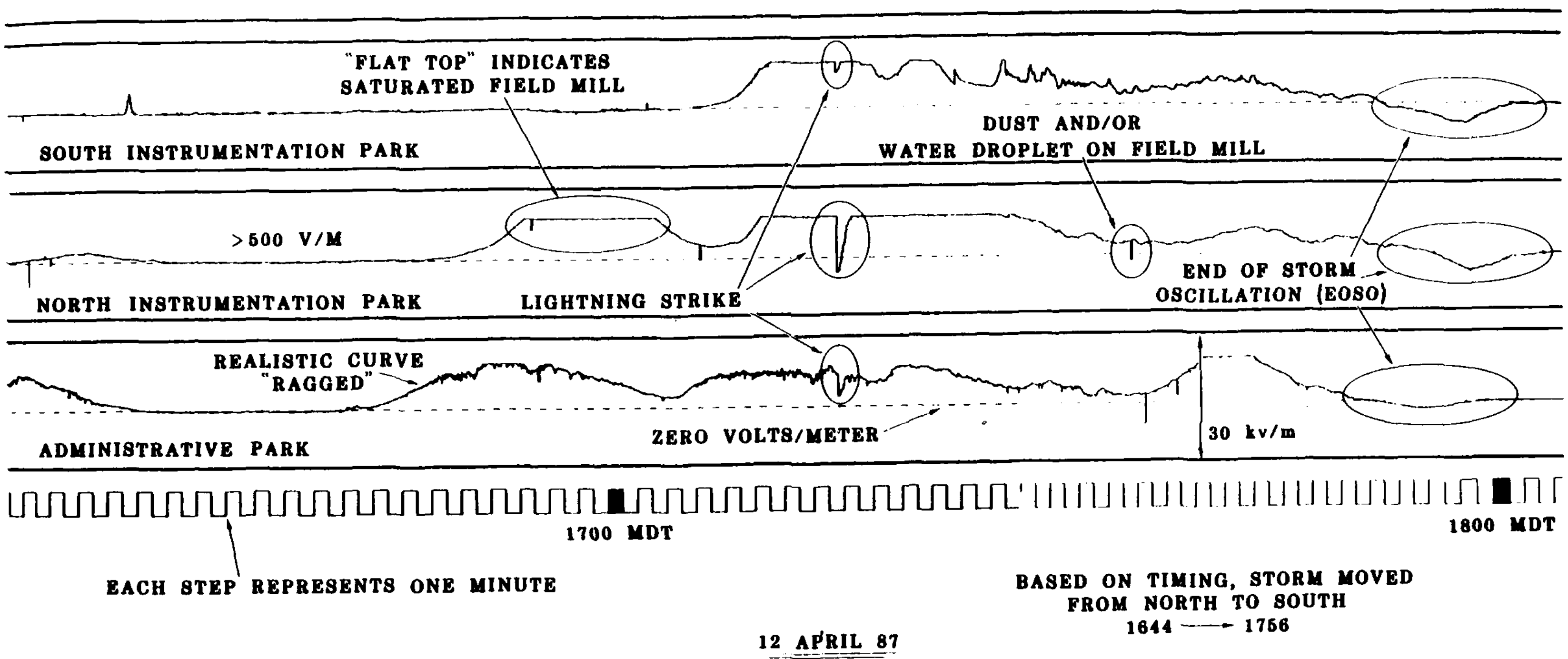
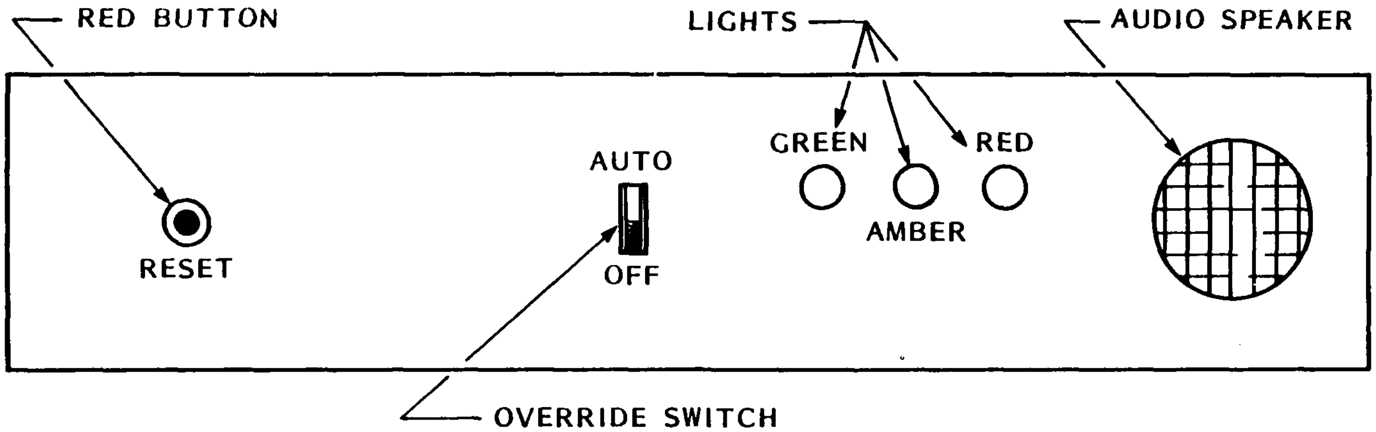


Figure A-2. Printer output (three locations).



SIGNAL MONITORING BOX
(LOCATED IN ADMINISTRATIVE TRAILER)

Figure A-3. Signal monitoring box (located in Administration trailer).

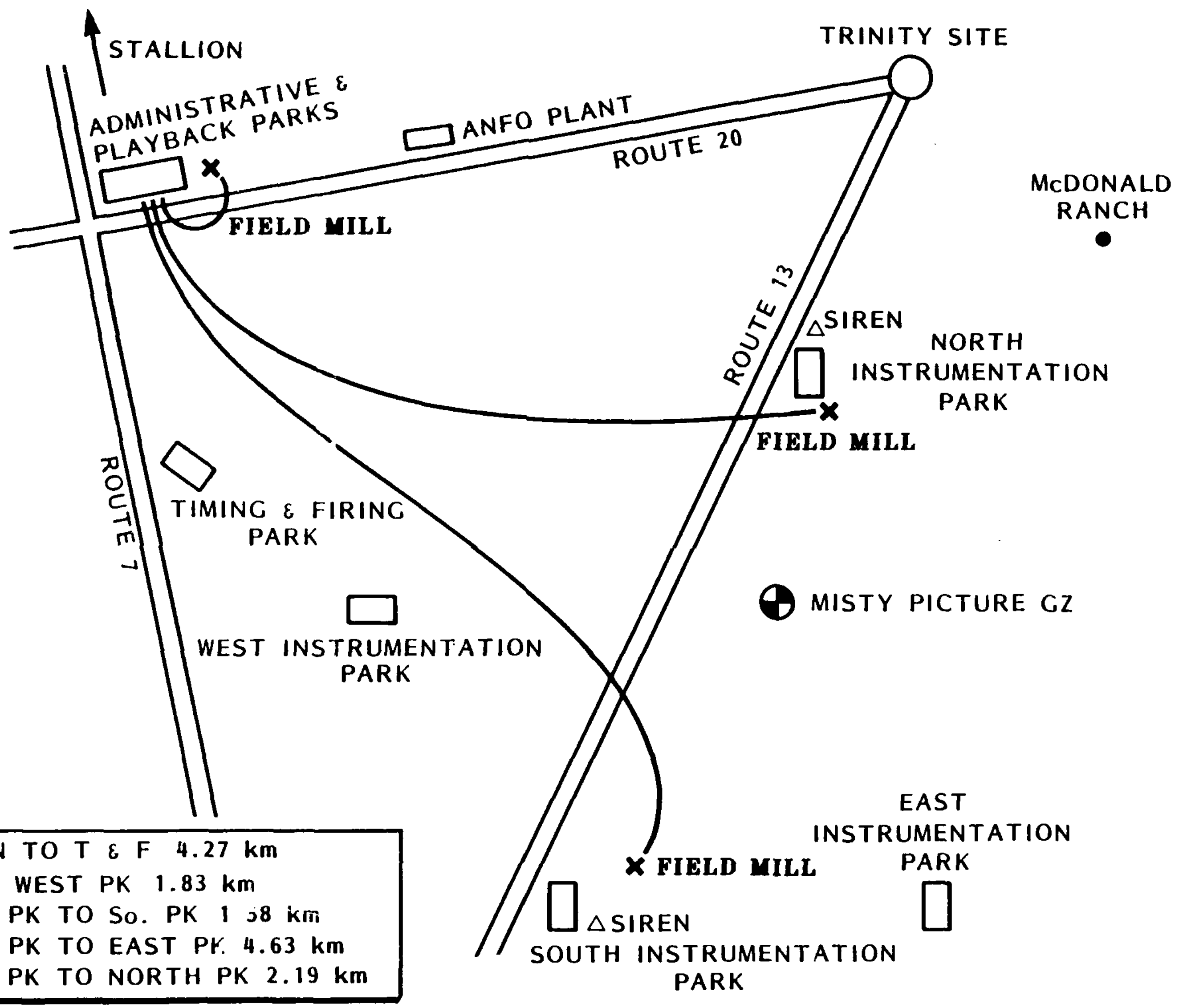


Figure A-4. Field Mill signal cable layout.

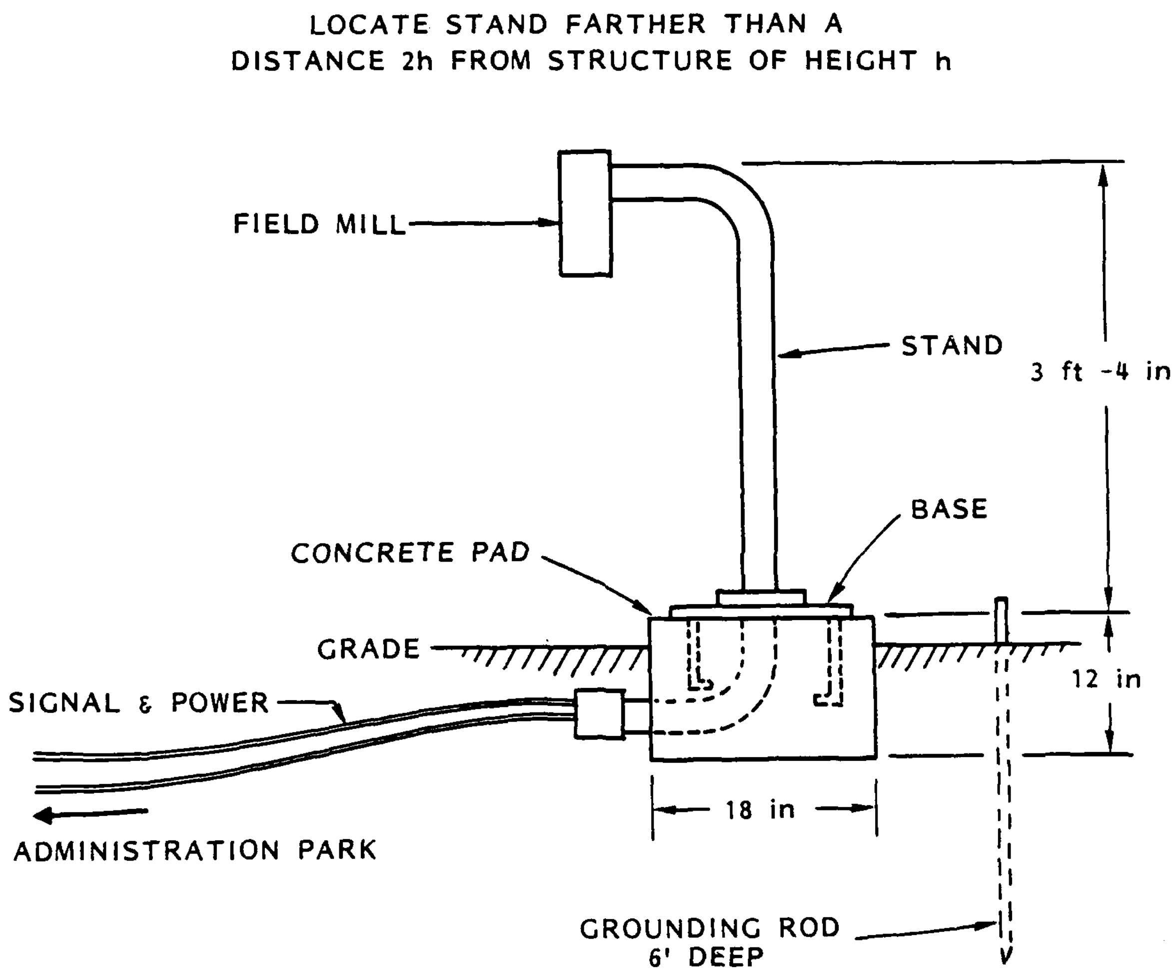


Figure A-5. Field mill installation.

the relays to turn on the sirens will close unless the override switch is down. When the field at any mill exceeds 2500 V/m, the red light will flash. After the fields have dropped below alarm levels, the alarms will stay on for an additional 30 min. The alarms may be turned off manually by pushing the reset button.

When the yellow light goes on and the printer starts printing, the operator should note the weather conditions to determine if a thunderstorm may be building or moving in. When the red light and the audible alarm go on, the operator should decide, based on observations of the weather, whether to allow the sirens to turn on (override switch up) or to keep the sirens off (override switch down).

Display Status	Action
Green Light	None
Yellow Light, Printer ON	Observe weather, prepare for possible thunderstorm
Red Light on, Audible Alarm,	Observe weather; determine whether to activate sirens (override switch up) or to disable sirens (override switch down)

Note: On the field mill chart for the North Instrumentation Park the lightning strike crosses the dashed zero line. For this system, this indicates the strike was probably within 460 m (1500 ft) of the field mill location.

Operation Sequence

Upon arrival at Administration Trailer:

1. Monitor Box - Switch from alarm to off.

2. Printer - Turn off power.

3. Monitor - Reset.

4. Printer - Turn on power.

5. Monitor - Reset (this will cause printer to print a Header containing date and time).

6. If at any time during the day the printer data becomes unintelligible, perform steps 2 thru 5.

7. During duty period (daytime) the system may detect a sufficient electric field to give alarm--this is indicated by either a yellow/amber light or red light on the monitor panel. The printer will also start printing. The operator should go outside and observe the sky. If the sky looks threatening, then the alarm switch should be switched to alarm. This action will cause two sirens (one at North Park and one at South Park) to sound if the field mill system is sensing a sufficiently strong electric field.

8. The system is designed to continue giving warning for 30 min after the last warning threshold was detected. If the operator's observation is that the storm is over, than all clear may be given before completion of the 30 min period. This is accomplished by performing steps 2 through 4.

9. Just before departure from the Administration Trailer:

    a. Repeat steps 2 through 5 above.
    b. Monitor Box - switch from off to alarm.
    c. Ensure guards know how to turn off sirens.

A-2. SIRENS

The sirens (two each, one at North Park and one at South Park) are Penetrator 50 rotating directional sirens. A 50 HP motor producing sound through direct drive rotor-stator design that radiates effectively in a 360 deg pattern.

PENETRATOR 50 SPECIFICATIONS	
Rated sound output at 100 ft* (db) (c scale)	135
Sound range at 70 dB (ft)	9000
Total circular coverage (sq.miles)	9.0
Output frequencies (Hz)	465-698
Sound dispersal	6° Above horizon 6° Below horizon
Rotation speed (r/m)	3 ± 0.5
Length, width, height (ft)	8 x 6 x 8
Weight (crated) (lbs)	2000

*Free field (nonreflective) measurement, add +3 dbc reflective sound in typical installations.

NOTE: The decibel rating of the ACA equipment discussed herein is based on testing done by independent laboratories under ideal conditions. Test results may vary depending on various factors, including weather conditions.

APPENDIX B

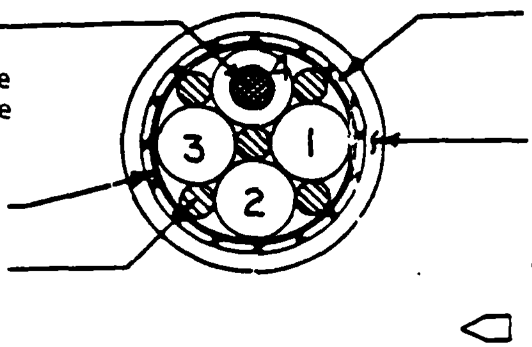
EXAMPLES OF SHIELDED CABLE SPECIFICATIONS

FOUR-CONDUCTOR, NO. 22 AWG, SHIELDED CABLE

B-1. GENERAL DESCRIPTION

This specification contains requirements for a four-conductor, No. 22 AWG, shielded cable with polyurethane sheath.

a. Construction



View of outer end of cable on shipping reel

Color Code:	Conductor No.	Color
	1	White
	2	Black
	3	Red
	4	Green

b. Application--this cable is designed for continuous operation at potentials up to 600 V RMS (850 V peak), and to withstand the following range of environmental conditions:

Temperature:	Nonflexing (Shipping and Storage):	up to +175°F
	flexing (Installation and Operation:	-20° to +175°F

Geophysical: Water, crude oil, drilling mud, sand, gravel, and liquid or set cement grout.

c. Testing--Measurements and tests shall be performed in accordance with the methods defined in DOD/DNA-NV-STD-7. Testing quantities shall be in accordance with Table B-1, Testing Chart, of this specification. Sampling shall consist of representative specimens (as specified in DOD/DNA-NV-STD-7) taken from two production lengths, separated by at least one such length, in each 50,000 ft or less, processed as a production lot.

B-2. DETAILS OF CONSTRUCTION

a. Insulated Wires (Conductor plus color coded insulation)

(1) Conductors--No. 22 AWG, 7 strands (minimum), tinned soft copper in accordance with MIL-W-16878. Approximate O.D. = 0.030 in.

Table B-1. Testing Chart.

		Quantity	
Characteristic	Requirement	100%	Sampling
Single-Insulated Wire:			
Voltage Withstand Test - or - Spark Test - or - Impulse Dielectric	2500 VDC or 1500 VRMS 5000 VDC or 3000 VRMS 15 kV (pulse)	X	
Cold Bend Test	-85°F (max.); Mandrel diameter, 2 in (max.); then pass Voltage Withstand Test (in water)		
Finished Cable:			
Conductor DC Resistance	17.1 Ω (max.)/1000 ft of finished cable	X	
Voltage Withstand Test	2500 VDC or 1500 VRMS	X	
Insulation Resistance Test (after Voltage Withstand Test)	200 MΩ (min.)·1000 ft of finished cable		
Capacitance: Single (Insulated Wire) to ground	40 pF (max.)/ft of finished cable		X
Spark Test (Cable Sheath)	4500 VDC or 3000 VRMS	X	
Marking Durability	150 Cycles (300 strokes) (min.)		X
Cold Bend Test	-20°F, 6 h, Mandrel diameter = 6 in (max.); then pass Voltage Withstand Test between conductors		X
Physical Properties of Cable Sheath	As specified in Section B-2 d.(1) this specification		X

(2) Insulation--A layer of propylene/ethylene copolymer in accordance with REA PE-210, Appendix A in solid colors and in accordance with the Munsell color charts for color coding, shall be applied as smooth, tight fitting and continuous sheath over the conductor. The wall thickness shall be 0.012 in minimum at any point. Concentricity shall be 70 percent minimum. (Approximate O.D. = 0.058 in.)

b. Cable Assembly--The color code shall be in accordance with Section B-1a. of this specification. The length of lay and the relative position of each of the four wires shall be the same throughout the length of any one cable.

(1) Central Member--A nonhygroscopic filler of solid rod, multimonofilament, or twisted film, having an effective diameter of approximately 0.24 in, shall be used as the cable's central member.

(2) First Layer--Four insulated wires shall be cabled together with a left-hand lay length of 1.5 to 2.0 in. Four nonhygroscopic fillers of solid rod, multimonofilament, or twisted film shall be used to fill the interstices and make the cable cross section circular. (Approximate O.D. = 0.140 in.)

(3) Barrier Tape--A polyester tape of 0.001 in nominal thickness and in accordance with MIL-I-631, Type G, Subform T_f, shall be applied as a smooth snug, spiral wrap over the cable bundle (in either lay direction) and shall lap itself between 40 and 48 percent. The lay angle shall be greater than 25 deg. (Approximate O.D. = 0.145 in.)

c. Overall Shield--A braid of No. 34 AWG (0.0063 in) tinned soft copper wires in accordance with ASTM B-33 shall be applied over the polyester barrier tape. The coverage shall exceed 93 percent and the braid angle shall be between 40 and 50 deg. (Approximate O.D. = 0.170 in.)

d. Cable Sheath--A sheath of black, polyurethane elastomer based on chemically modified polytetramethyleneether glycolmethylene bis (4 phenyl-diisocyanate) having the following physical properties after application to the cable shall be applied as a smooth, tight fitting and continuous sheath over the overall shield. The wall thickness shall be .028 in minimum average and 0.025 in, minimum at any point. Concentricity shall be 70 percent minimum. (Finished cable O.D. = 0.235 ± 0.015 in.)

(1) Physical Properties of cable sheath--

Durometer A (3 s)	82/88
Tensile Modulus	340
lb/in^2 at 10% elongation, min.	800
lb/in^2 at 100% elongation, min.	1600
lb/in^2 at 300% elongation, min.	5000
% elongation at break, min.	450
Set after 200% elongation, max.	22%
Tear Strength, min. lb/in	130
Brittle Point	<-80°F
Tensile Strength, max. change after conditioning (168//0/95:T-70/95 (ASTM D-618)	-20%

e. Sheath Marking--The following identification shall be marked on the cable sheath at intervals of not more than five feet, using ink of a contrasting color. Characters shall be 1/16 in, minimum height.

"Manufacturer's Name 198_DOD/DNA-MC-12 No. 22 AWG 040265BS (QUAD)"

B-3 APPLICABLE DOCUMENTS

a. U.S. Department of Defense/Defense Nuclear Agency Specifications--DOD/DNA-NV-STD-7, specification for testing methods for Multiconductor Cable.

b. American Society for Testing and Materials Specifications (ASTM)--ASTM B-3-63 (Reapproved 1969), specification for soft or annealed Copper Wire. ASTM B-33-63 (Reapproved 1969), specification for tinned soft or annealed Copper Wire for electrical purposes. ASTM D-618-61, conditioning plastics and electrical insulating materials for testing.

c. Military Specifications--MIL-I-631D (November 1961), (Amendment 5, June 20, 1968), insulation, electrical, synthetic resin composition nonrigid. MIL-W-16878D (January 16, 1961), (Amendment 1, June 15, 1967), wire, electrical, insulated high temperature.

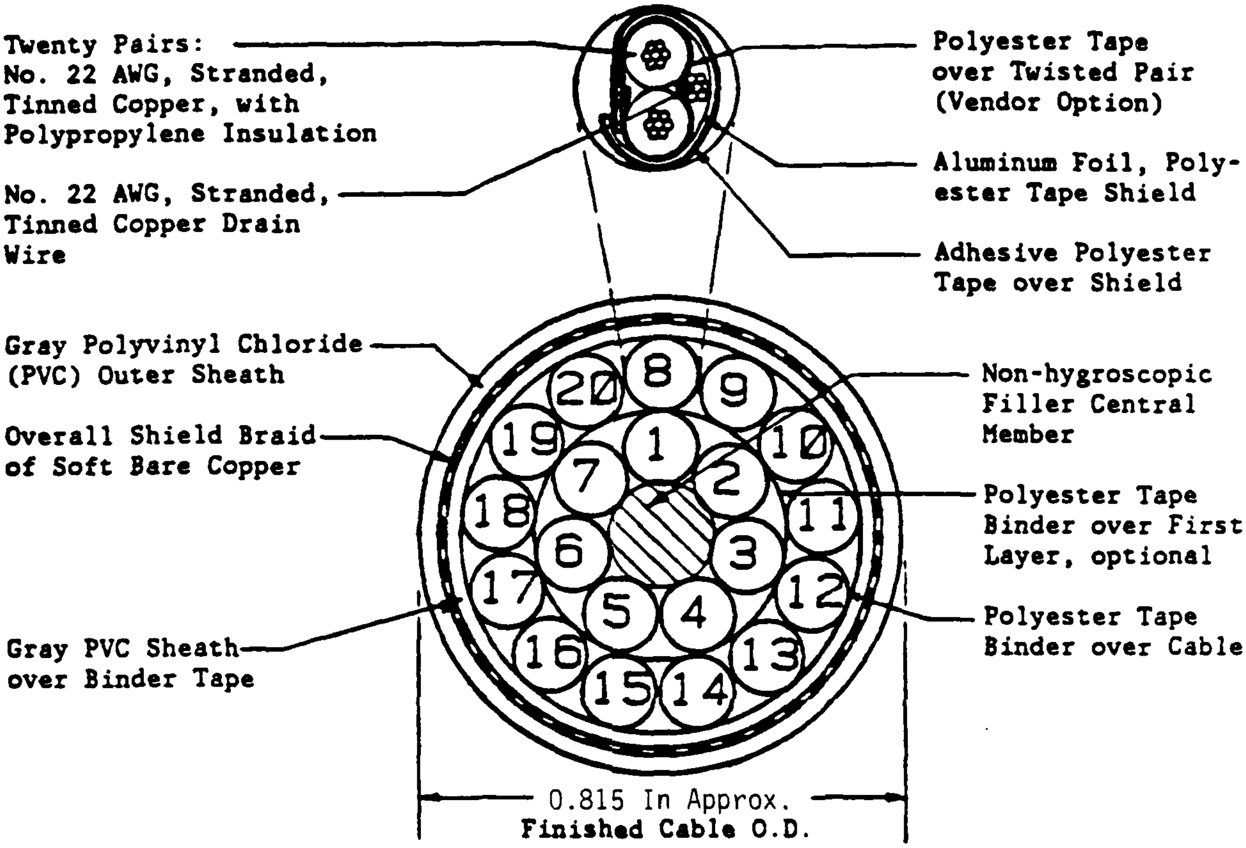
d. Rural Electrification Administration Specifications--REA PE-210 (April, 1967), Crystalline Propylene/Ethylene Copolymer Ray Material.

e. Commercial Standards--Munsell color charts for color coding.

B-4. TWENTY SHIELDED PAIR, NO. 22, CABLE

a. General Description--The cable consists of 20-pair shielded (40 conductor), No. 22 AWG, with a polyvinyl chloride (PVC) inner sheath, an overall shield, and a gray PVC outer sheath.

(1) Construction--View of outer end of cable reeled for shipping



Color Code:

Pair No.	Color	with Color	Pair No.	Color	with Color
1	White	Blue	11	Black	Blue
2	White	Orange	12	Black	Orange
3	White	Green	13	Black	Green
4	White	Brown	14	Black	Brown
5	White	Slate	15	Black	Slate
6	Red	Blue	16	Yellow	Blue
7	Red	Orange	17	Yellow	Orange
8	Red	Green	18	Yellow	Green
9	Red	Brown	19	Yellow	Brown
10	Red	Slate	20	Yellow	Slate

(2) Application--This cable is designed for continuous operation at potentials up to 600 VAC, and to withstand the following range of environmental conditions:

Temperature:	Nonflexing (Shipping and Storage)	up to +165°F
	Flexing (Installation and Operation)	-20°F to +165°F

Geophysical: Water, crude oil, drilling mud, sand gravel, and liquid or set cement grout.

B-5 TESTING

Single Insulated Wires		Quantity	
Characteristic	Requirement	100%	Sampling
Impulse Dielectric Test	Zero faults before cabling: 15,000 V (pulse)	X	
or - Spark Test	6,000 VDC or 2,000 VAC	Any 1 of 3	
or - voltage Withstand Test in Water	6,000 VDC or 2,000 VAC	options	
Cold Bend Test	-22°F or colder; Mandrel dia. = 2 in (max.); then pass Voltage Withstand Test (in water)		X
Heat Resistance Test	+266°F (min.); 96 h. Mandrel dia. = 2 in (max.); then pass Voltage Withstand Test (in water)		X

B-5 TESTING (Concluded)

	Finished Cable	Quantity	
Characteristic	Requirement	100%	Sampling
DC Resistance at 68°F	Maximum ohms per 1000 ft: 17.1 Ω; each insulated wire 15.0 Ω; each drain wire	 X X	
Voltage Withstand Test	6,000 VDC or 2,000 VAC: Each insulated conductor, and each pair shield	X	
Insulation Resistance Test	Before Voltage DC Withstand Test or after Voltage AC Withstand Test, measured megohms of: Each insulated wire shall exceed 10,000,000 divided by feet included in measurement. Each complex shield (drain wire) shall exceed 100,000 divided by feet included in measurement	X X	
Cable Jacket: Spark Test	6,000 VDC or 2,000 VAC	X	
Visual Examination	Conformance to specified dimensional tolerances, and all aspects of good workmanship applicable to cable.		X

a. Testing Methods--Measurements and tests shall be performed in accordance with the methods defined in DOD/DNA-NV-STD-7.

b. Testing Qauntities--Designated 100 percent tests or measurements shall be performed on the entire length of every piece of this cable offered for shipment. Designated sampling tests or measurements shall be performed on specimens taken from two production lengths, separated by at least one such length, in each 50,000 ft or less processed as a production lot.

The specimens for sampling tests may consist of entire reel-lengths of cable, or shorter lengths cut from the cable offered for shipment. The length of specimen(s) actually used shall be as required to perform each test in the manner prescribed, and with the resolution specified in DOD/DNA-NV-STD-7.

c. Source Inspection Requirements--Source inspection(s) shall be performed by the purchaser or the purchaser's authorized representative to verify that the cables offered for shipment meet the requirements of this specification, and he shall have the right to select the cables to be tested and to witness any part or all of the specimen preparation or testing. He also shall have a right to permanent possession of a copy of all test and measurement data obtained from an inspection lot offered for final inspection whether or not he witnesses the testing or records the information himself.

B-6 DETAILS OF CONSTRUCTION

a. Insulated Wire--(40 Required)

(1) Conductor--The conductor shall be No. 22 AWG, 7 strands/0.0100 in diameter, tinned soft copper in accordance with Federal Specification QQ-W-343. (Approximate O.D. = 0.030 in.)

(2) Insulation--A layer of propylene/ethylene copolymer in accordance with REA-PE-210, Appendix A, in solid colors in accordance with the EIA Standard RS-359 for Color Coding, shall be applied as a smooth, tightly-fitting, continuous sheath over the conductor. The nominal wall thickness shall be 0.012 in ± 0.002 in. Concentricity shall be not less than 70 percent. (Approximate O.D. = 0.054 in.)

Color Code: 5-White, 5-Red, 5-Black, 5-Yellow, 4-Blue, 4-Orange, 4-Green, 4-Brown, 4-Slate.

b. Drain Wire--The drain wire shall be No. 22 AWG, 7 strands/0.0100 in diameter, tinned soft copper in accordance with Federal Specification QQ-W-343. (Approximate O.D. = 0.030 in.)

c. Pair Complex--(Twenty Required)

(1) Pair Assembly--Two No. 22 AWG insulated wires in accordance with Section B-6a. of this specification shall be twisted together with a right-hand lay length of 0.70 to 1.00 in. Color code shall be as specified in Section B-4a.(1) of this specification.

(2) Separator--A polyester tape of 0.0005 in nominal thickness, in accordance with MIL-I-631, Type G, Subform T(f), may be applied, as a vendor option, in a right-hand direction with a minimum lap of 15 percent.

(3) Drain Wire--One No. 22 AWG drain wire, in accordance with Section B-6b., shall be applied in one interstice.

(4) Shield--A shield of aluminum foil of 0.00035 in thickness on a polyester tape of 0.001 in nominal thickness, per MIL-I-631, Type G, Subform T(f), shall be applied with the aluminum foil side inward in a right-hand lay direction and shall lap at a minimum of 15 percent. (Approximate O.D. = 0.114 in.)

(5) Complex Jacket--A polyester tape of 0.0015 in nominal thickness, in accordance with MIL-I-631, Type G, Subform T(f), having a pressure-sensitive coating on one side, shall be applied with the adhesive inside as a smooth spiral wrap over the shield. The tape shall lap at a minimum of 25 percent and be applied in a right-hand lay direction. (Approximate O.D. = 0.120 in.)

d. Cable Assembly--Cabling shall be done using equipment (such as planetary) which imparts no twist to the individual complexes. The color-coded pair complexes shall be arranged as specified in Section B-4a.(1) of this specification.

(1) Central Member--A nonhygroscopic filler of solid rod, multimonofilament, or twisted film, having an effective diameter of 0.147 to 0.153 in, shall be used as the central member of the cable.

(2) First Layer--Pairs No. 1 through No. 7 shall be cabled around the central member at 3.5 to 4.5 in right-hand lay. A polyester tape binder may be used at the manufacturer's option. (Approximate O.D. = 0.366 in.)

(3) Second Layer--Pairs No. 8 through No. 20 shall be cabled around the first layer at 6.5 to 8.0 in left-hand lay. (Approximate O.D. = 0.580 in.)

(4) Binder Tape--A polyester tape of 0.001 in nominal thickness and in accordance with MIL-I-631, Type G, Subform T(f) shall be applied as a smooth spiral wrap over the second layer of cabled pairs. The tape shall be applied (in either lay direction) and shall lap at a minimum of 40 percent. (Approximate O.D. = 0.585 in.)

e. Inner Sheath--A layer of gray polyvinyl chloride in accordance with MIL-I-631, Type F, Grade a, Class I, shall be applied as a smooth, tightly-fitting, and continuous sheath over the tape-wrapped cable. The nominal wall thickness shall be 0.040 in ± 0.005 in. Concentricity shall be not less than 70 percent. (Approximate O.D. = 0.665 in.)

f. Overall Shield--A braid of No. 34 AWG (0.0063 in diameter) bare soft copper wires in accordance with ASTM B 3 shall be applied over the inner sheath. Braid construction shall be in accordance with one of the following alternates.

No. of carriers:	24	36	48
No. of ends:	15	10	8
Picks per inch:	5.3 to 5.8	8.0 to 8.7	10.6 to 11.6

Engineering information: Braid coverage is between 93 and 97 percent.
Braid angle is between 43 and 46 deg.
(Approximate O.D. = 0.695 in.)

g. Outer Sheath--A layer of gray polyvinyl chloride in accordance with MIL-I-631, Type F, Grade a, Class I shall be applied as a smooth, tightly-fitting, and continuous sheath over the outer shield braid. The nominal wall thickness shall be 0.060 in ± 0.006 in. Concentricity shall be not less than 80 percent. The manufacturer shall extrude to wall thickness in lieu of cable O.D. (Approximate Cable O.D. = 0.815 in.)

h. Cable Identification--The following identification shall be marked on the cable jacket at intervals of not more than 5 ft, using ink of a contrasting color. Characters shall be at least 1/8 inch high:

"DOD/DNA-MP-21, Rev. 1, 20 SHLD PR No. 22, Name of Manufacturer, Month and Year of Manufacture."

B-7. APPLICABLE DOCUMENTS

a. Department of Defense/Defense Nuclear Agency (DOD/DNA) Specification--

DOD/DNA-NV-STD-7 (Latest Revision)	Test Methods for Multiconductor Cables

b. American Society for Testing and Materials (ASTM) Standards--

ASTM B 3-74 (Reapproved 1980)	Standard Specification for Soft or Annealed Copper Wire

c. Federal Specification--

QQ-W-343E (Nov. 13, 1981) (Amendment 1: Jan. 24, 1984)	Wire, Electrical, Copper (Uninsulated)

d. Military (MIL) Specification--

MIL-I-631D (November 1961) (Amendment 5: June 20, 1968)	Insulation, Electrical, Synthetic-Resin Composition, Nonrigid

e. Rural Electrification Administration (REA) Specification--

REA PE-210 (April 1967)	Crystalline Propylene/Ethylene Copolymer Raw Material

f. Commercial Standard--

Electronic Industries Association (EIA) Standard RS-359-68 Reapproved 1978)	EIA Standard Colors for Color Identification and Coding

APPENDIX C

EARTH GROUND TESTING

Earth grounding is defined as the process by which an electrical connection is made to the earth. The earth electrode subsystem is that network of rods, wires, or other configuration of metals which establishes electrical contact between the elements of the facility and the earth. This system should achieve the following objectives:

- Provide a path to earth for the discharge of lightning strokes in a manner that protects the structure, its occupants, and the equipment inside.

- Restrict the step-and-touch potential gradient in areas accessible to persons to a level below the hazardous threshold even under lightning discharge or power fault conditions.

- Assist in the control of noise in signal and control circuits by minimizing voltage differentials between the signal reference networks of separate facilities.

Table C-1 provides a matrix of the purposes, requirements, and design factors considered for a facility ground system.

According to handbook (Ref. 3) tables for resistivity values of earthing mediums, a sand and gravel medium such as found at the PHETS facility has resistivity bounds of 5×10^3 Ω-cm to 10^5 Ω-cm. Using the test data shown in Fig. C-1 it is possible to determine the earth resistivity near the surface, i.e., less than 610 cm (20 ft) deep.

For a vertical, buried rod the empirical expression for resistance to earth is

$$R = 0.366 \frac{\rho}{\ell} \log \frac{3\ell}{d} \qquad \text{(C-1)}$$

Table C-1. Facility Ground System: Purposes, requirements, and design factors.

Subsystem	*Purpose*	*Requirements*	Design Factors
Lightning Protection	Dissipate lightning energy in earth.	Multiple connections to earth electrode subsystem, high peak power transfer capability, low impulse impedance to minimize magnitude of transient potential.	Lightning protection subsystem must be sized to dissipate energy in a lightning pulse (worst case) without producing hazardous voltages or damage to itself.
Fault Protection	Provide fault current path to operate equipment breakers, blow fuses, etc.	Low resistance in the return path for fault current, maintain voltage of equipment enclosures near earth potential.	Resistance should be low enough to permit operation of facility over-current devices when faults occur.
Signal Reference	Reduce noise in signal circuits, provide leakage path for static charges, establish voltage reference.	Establish reference potential for signal voltages, provide sink for static charge.	Fault currents and lightning protection system currents *normally should not flow* in the signal reference network; earth connection should not degrade signal quality.
Earth Electrode	Low resistance path to earth.	Provides link for lightning protection, fault protection and signal reference subsystems to earth.	Installed around periphery of building or tower to be protected.

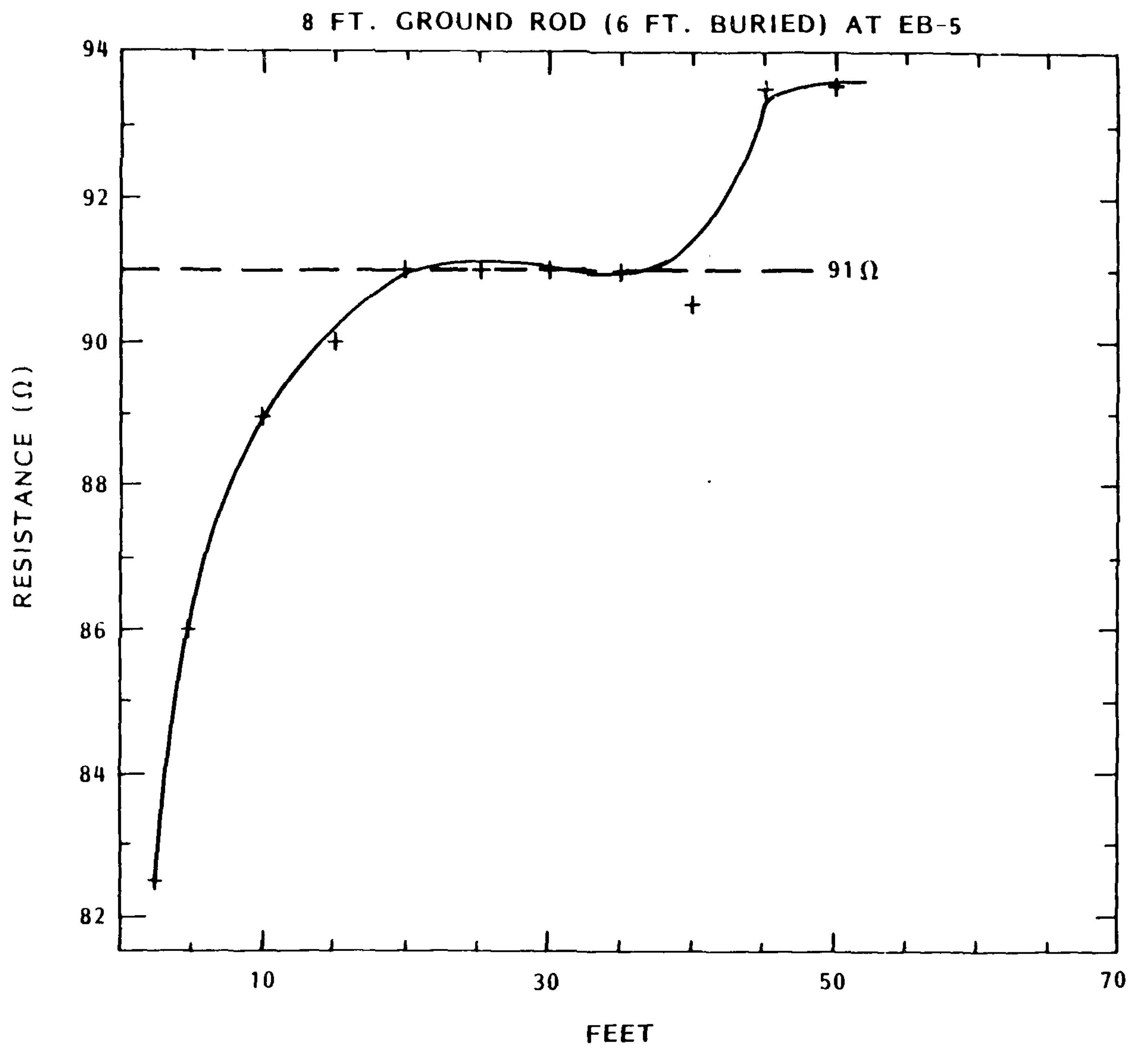


Figure C-1. 8 ft. ground rod.

where

R = resistance
ρ = earth resistivity, in Ω-cm
ℓ = rod length, in cm
d = rod diameter, in cm

The measured resistance, using the "Megger" ground tester, of the 1.9 cm (3/4 in) diameter copper plated steel rod driven 188 cm (74 in) into the ground was 91 Ω. Hence, the earth resistivity

$$\rho = \frac{R\ell}{0.366 \log \frac{3\ell}{d}} \quad \text{or } \rho = 18{,}905 \ \Omega\text{-cm} \qquad \text{(C-2)}$$

For the 46-m (150 ft) earth ground well at EB-5, the measured resistance was 2.6 Ω (see Fig. C-2). For the 46-m (150 ft) earth ground well at WB-2, the measured resistance was 3.5 Ω (see Fig. C-3).

Using the greater resistance of these two, then the resistivity using the vertical rod (Eq. C-2) formula is

$$\rho = 11{,}334 \ \Omega\text{-cm} \qquad \text{(C-3)}$$

From these values we see that useful values for resistivity are 19 x 10^3 Ω-cm for near surface installations and 11 x 10^3 Ω-cm for deep buried earth grounds at the PHETS facility.

Figures C-4 and C-5 show the measured resistance data for the East Bunker-5 and West Bunker-2, each disconnected from the 46-m (150 ft) earth ground well.

If it is assumed that a buried circular plate is a good approximation for the bermed cylinder then the emperical formula

$$R = 0.125 \ \frac{\rho}{r_e} \left(1 + \frac{r_e}{2.5h + r_e}\right) \qquad \text{(C-4)}$$

is applicable where

R = resistance, in Ω
ρ = earth resistivity, in Ω-cm
h = depth of burial, in cm
r_e = effective radius, in cm

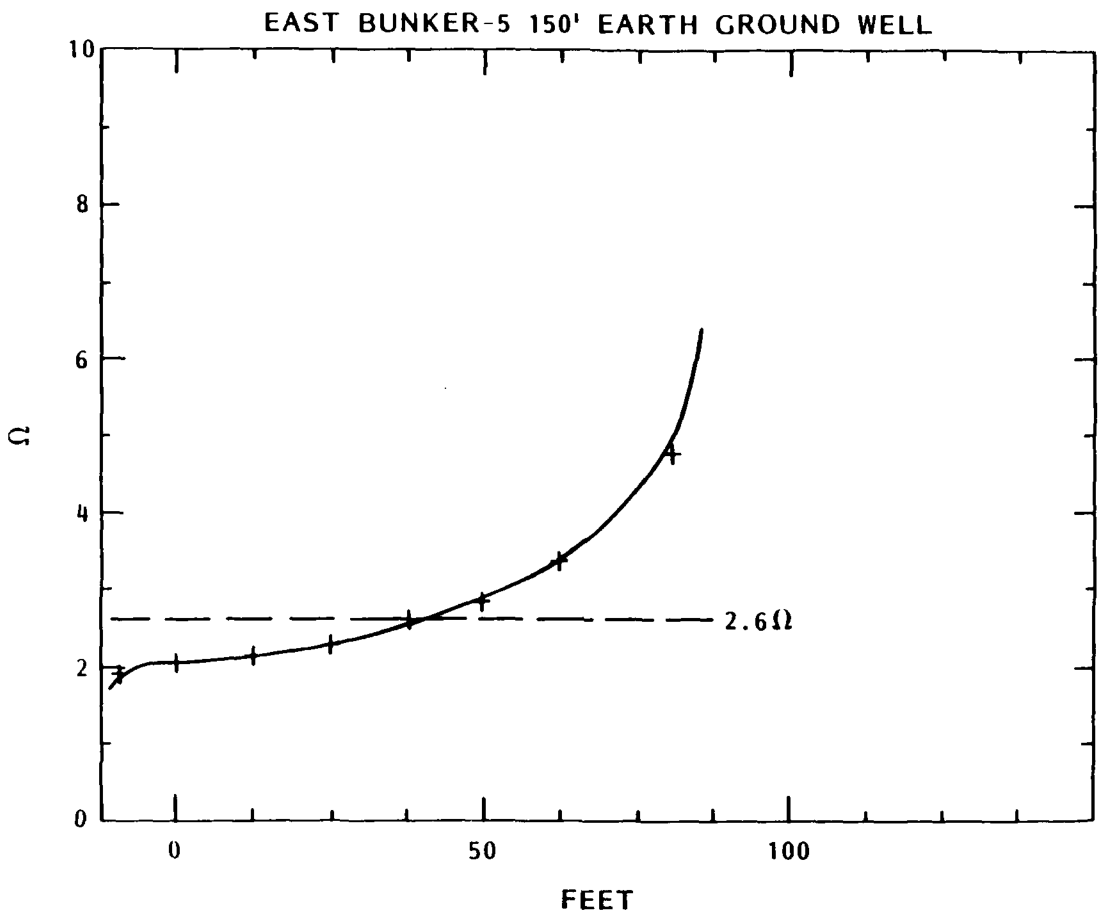


Figure C-2. EB-5 ground well.

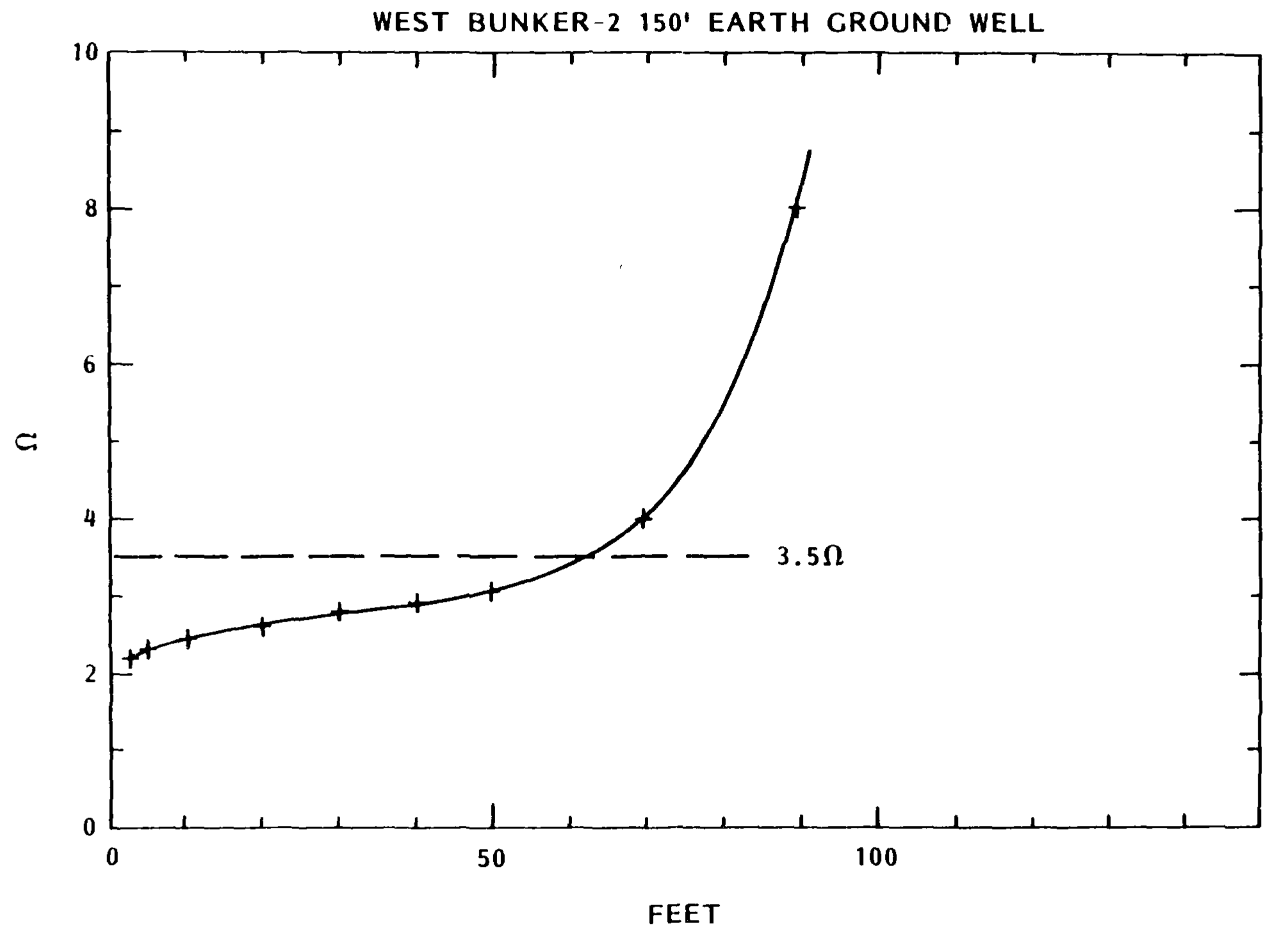


Figure C-3. WB-2 ground well.

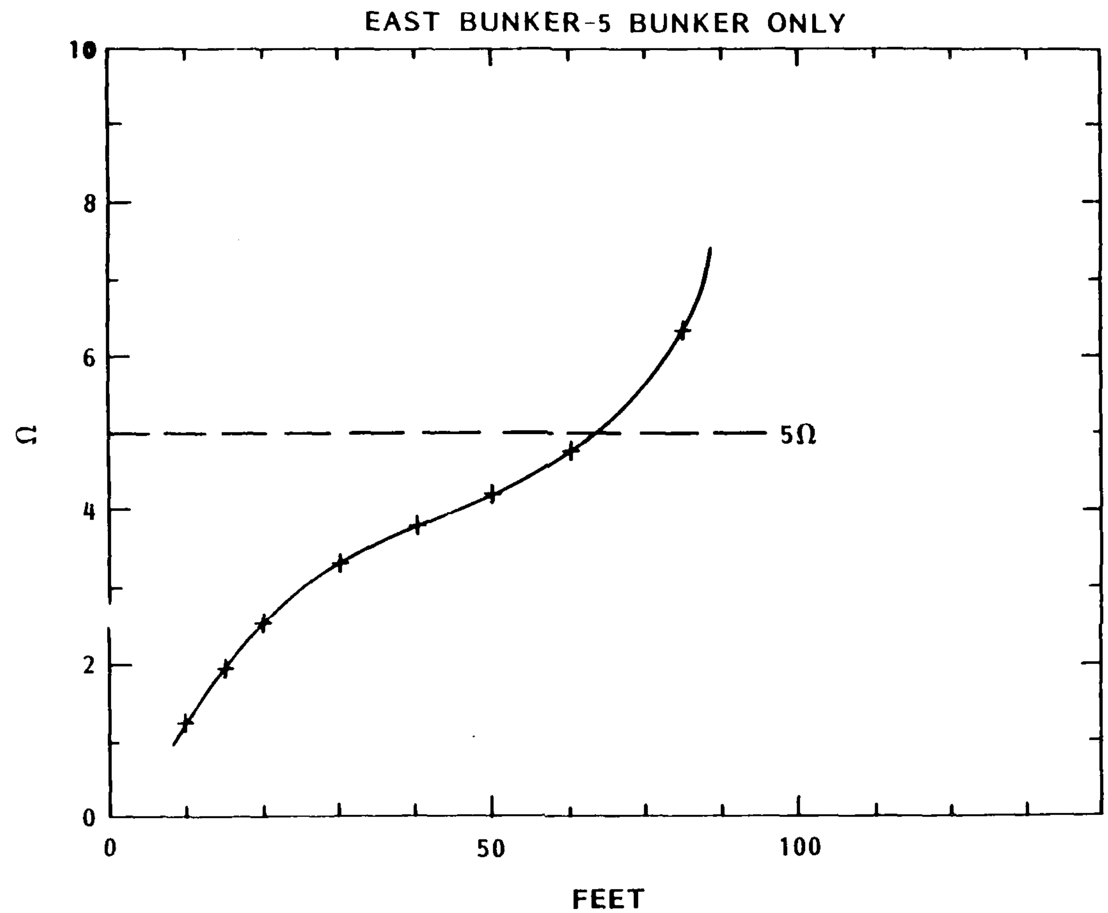


Figure C-4. EB-5 bunker.

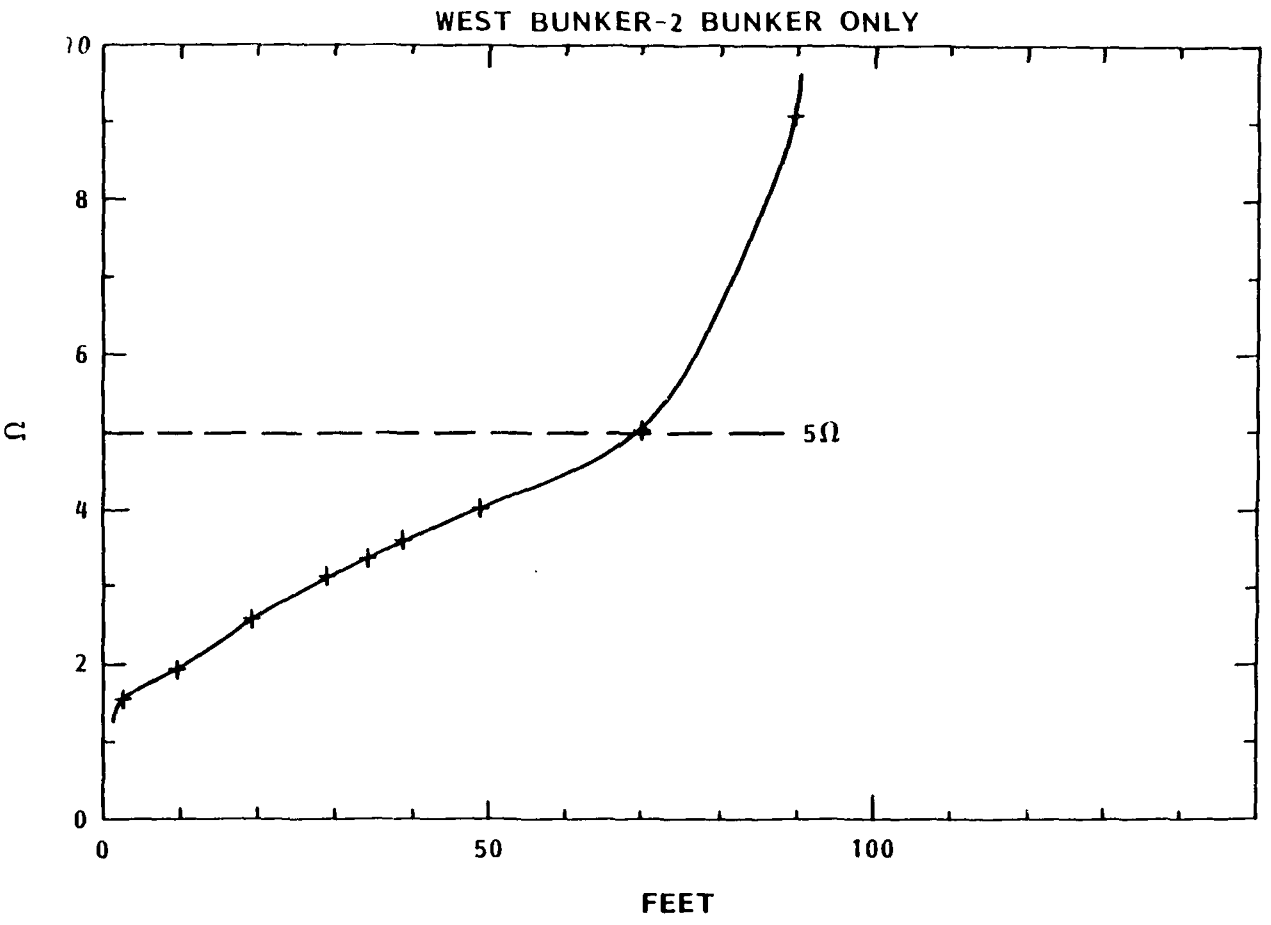


Figure C-5. WB-2 bunker.

$$r_e = \sqrt{\frac{A}{\pi}} \tag{C-5}$$

where

$$A = \frac{\pi DL}{2} \tag{C-6}$$

where D = bermed cylinder diameter

L = bermed cylinder length

then

$R = 7.5\ \Omega$

when $h = 213$ cm (7 ft)

$\rho = 19 \times 10^3\ \Omega$-cm

Now, from the points at which the measured values for EB-5 and WB-2 have a very steep slope (worst case)

$R = 5\ \Omega$

then

$\rho = 12{,}163\ \Omega$-cm

In summary, the resistances are as follows:

- for the 46 m (150 ft) earth ground wells at any PHETS location the resistance to earth is approximately 3.5 Ω and the earth resistivity is approximately $11 \times 10^3\ \Omega$-cm

- for a copper plated steel rod driven approximately 183 cm (6 ft) into the ground the resistance to earth is approximately 91 Ω and the earth resistivity is approximately $19 \times 10^3\ \Omega$-cm

- for the bermed instrumentation bunker treated as a buried flat plate the resistance to earth is approximately 5 Ω and the earth resistivity is approximately 12×10^3 Ω-cm

The primary conclusion here is that the stand alone bermed instrumentation bunker provides a resistance to earth less than the 10 Ω required by MIL-STD-188-124A and hence, the 46-m (150 ft) earth ground wells are not needed.